17-18

UNIVERSITY OF MICHIGAN
APR 11 1956
PUBLIC HEALTH LIBRARY

AMERICAN

Industrial Hygiene

ASSOCIATION

Quarterly

VOLUME 17, NUMBER 1
MARCH, 1956

LOOK TO DETREX FOR Service WITH A Saving

Value Sign

IN SOLVENT DEGREASING

There are three basic reasons why you get more value in Detrex equipment.

First, no other company can match Detrex experience in solvent degreasing . . . in fact a Detrex development (the art of stabilizing chlorinated solvents) originally made possible modern solvent degreasing. Today, Detrex produces more equipment for use with chlorinated solvents than any other company.

Second, Detrex is the only manufacturer of degreasing equipment who is also a basic producer of solvent . . . industry's *largest* direct supplier of trichlorethylene. Thus, Detrex engineers, chemists, field technicians alike fully understand both the behavior of solvent as well as the operation of the equipment in which it is used.

Third, Detrex service does not stop with installation of equipment but continues, free of charge, for as long as the operation exists. A large, competent staff of Detrex technicians is dedicated to this important work.

All in all, you can't match the benefits that accrue to Detrex customers. And that is the reason why industry prefers equipment that bears the name Detrex . . . it is truly the value sign in solvent degreasing.

DETREX CORPORATION

DEPT. E-311, BOX 501, DETROIT 32, MICH.

AMERICAN

INDUSTRIAL HYGIENE

ASSOCIATION

Quarterly

Volume 17 | MARCH, 1956 | Number 1

Public Health
RA
421
.A415

THIRD INDUSTRIAL NOISE CONFERENCE
Noise Reduction by Absorption, Shielding and Isolation ..... *Vaughn H. Hill* 17
Noise Reduction at the Source ..... *W. F. Scholtz* 19
Noise Reduction on a Large Gear Reducer by Use of a Resonator-Type Enclosure ..... *John J. Meyers* 22
Constructing a Class Room in a Noisy Area ..... *M. C. Skinner* 27
Noise Reduction at Scrap Handling Tubs and at the Controls of a Scrap Baler ..... *Jack C. Radcliffe* 29
Noise Reduction at Chipping Operations on Large Castings ..... *J. H. Botsford* 31
Reducing Impact Noise from Falling Parts ..... *Walter H. Konn* 33
Noise Reduction at a Hammer Mill and a Knife Cutter ..... *Russell S. Hunt* 35
An Approach to the Noise Problem in a Large Machine Shop ..... *William Pruessman* 37
Mechanics of an Industrial Hearing Conservation Program ..... *S. J. Rosica* 39
The Practical Aspects of Ear Protection ..... *Aram Glorig, M.D.* 43
Lockheed's Ear Protection Program ..... *J. F. Hatton* 48
Practical Aspects of a Hearing Conservation Program ..... *James R. Sheehan* 49
Ryan's Hearing Conservation Program ..... *Adolph Bolger* 52
One Approach to Hearing Conservation ..... *Richard Wilkins* 54
What We Know and Don't Know About Noise Control .... *Charles R. Williams* 55
Present State of Development of Muff-Type Ear Protectors .. *W. B. Wadsworth* 56
Summary of the Proceedings ..... *Herbert T. Walworth* 58

IODOMETRIC MONITORING OF BORON-CONTAINING ATMOSPHERES ..... *William H. Hill, Ph.D., George J. Levinskas, Ph.D., William J. Novick, Jr., B. S.* 61

FREE SILICA IN INDUSTRIAL DUSTS—PHYSICAL METHODS FOR DETERMINATION ..... *J. K. Brasch, M.S.* 65

THE COLLECTION OF SUBMICRON PARTICLES BY ELECTROSTATIC PRECIPITATION ..... *David A. Fraser, M.S.* 75

ESTIMATING AIRBORNE RADIOACTIVE PARTICULATE HAZARDS—A REVIEW OF SAMPLING CRITERIA ..... *T. J. Burnett and T. F. Hatch* 80

RADON DAUGHTERS IN MINE ATMOSPHERES—A FIELD METHOD FOR DETERMINING CONCENTRATIONS ..... *Howard L. Kusnetz, M.S.* 85

RADIOACTIVE WASTE DISPOSAL FOR THE SMALL ISOTOPE USER ..... *Herman Cember* 89

PRESIDENT'S PAGE ..... *N. V. Hendricks* 92

HYGIENIC GUIDE SERIES 93

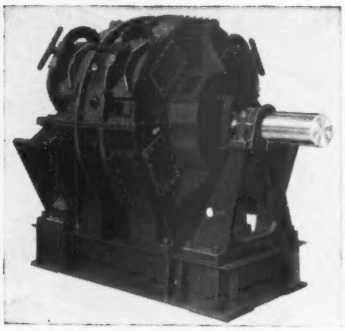
NEWS OF THE LOCAL SECTIONS 100

AIHA OFFICERS, DIRECTORS AND COMMITTEES 103

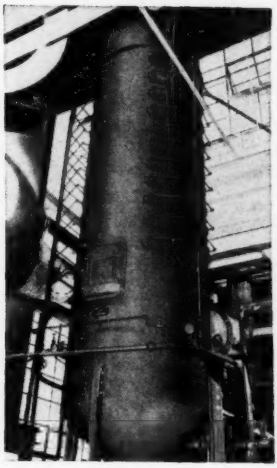
AMERICAN INDUSTRIAL HYGIENE ASSOCIATION QUARTERLY, published by the American Industrial Hygiene Association in March, June, September, and December. HOWARD N. SCHULZ, Editor; HERBERT J. WEBER, Advisory Editor; LLOYD E. GORDON, Associate Editor; JAMES A. MARTIN, Advertising Editor; CHARLES WYMAN, Circulation Editor; A. D. CLOUD, Publisher; DORIS FLOURNOY, Editorial Assistant. Publication and Editorial Offices, 605 North Michigan Avenue, Chicago 11, Illinois. Subscription $4.00 per year in the United States; $4.50 per year in Canada; $5.00 per year in other countries. Single copies, $1.50. Copyright, 1955, the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION. Entered as second class matter May 3, 1948, at the post office at Sheboygan, Wisconsin, under the Act of March 3, 1879. The AMERICAN INDUSTRIAL HYGIENE ASSOCIATION QUARTERLY reserves the right to edit all advertisements and to refuse advertising copy when it does not meet the high professional standards adopted by the Association.

How "BUFFALO" Can Help You with your *AIR CLEANING* Jobs

Public Health



"Buffalo" Rotary Gas Scrubber



"Buffalo" Hydraulic Scrubbing Tower

With the country becoming more and more pollution-conscious, industry calls on Engineers with many "puzzlers" in the way of air-cleaning problems. Here at "Buffalo", with over half a century of experience in this field — and a wide line of equipment — we are in an excellent position to help. Our files include a tremendous variety of problems successfully solved, with new information being added almost daily. "Buffalo" Engineers are constantly developing highly specialized equipment for new and specialized problems.

EXAMPLE—a collection efficiency of 99.9% plus, ending a serious nuisance problem in phosphate rock drying operations.

EXAMPLE—1000° F. highly corrosive gas effluent made nuisance-free and non-toxic.

EXAMPLE—tar vapor, lampblack, metallic fume in concentrates of 5 to 10 grains/cu. ft. removed to average of .006 grains per cu. ft. in numerous installations.

WRITE FOR BULLETINS AP-225, AP-425, AP 525, 3181-B, and 2424-F.

"Buffalo" equipment includes Air Washers, Hydraulic Scrubbing Towers, Hydro-Volute Scrubbers, Rotary Multi-stage Gas Scrubbers, Gas Absorbers, Blowers, Exhausters and Pumps to solve most any cleaning problem you may have — all engineered to the job, for highest efficiency and simplest possible maintenance. Call on the "Buffalo" Air Engineer in any principal city for sound, helpful recommendations.

"Buffalo" SALES ENGINEER AIR CLEANING

BUFFALO FORGE COMPANY

183 MORTIMER ST. BUFFALO, N. Y.

Canadian Blower & Forge Co., Ltd., Kitchener, Ont.
Sales Representatives in all Principal Cities

"Buffalo"

Air Cleaning Equipment

Ventilating Air Cleaning Air Tempering Induced Draft Exhausting Forced Draft Cooling Heating Pressure Blowing

Third Industrial Noise Conference

Sponsored by the Associated Industries of New York State Buffalo, New York, November 15, 1955

THE FOLLOWING papers were presented at the Third Industrial Noise Control Conference sponsored by the Associated Industries of New York State, Inc., through its Technical Committee on Noise in Industry. About 450 plant engineers, industrial hygiene personnel, medical directors, personnel managers and other plant management personnel representing about 125 industrial units and about 15 states attended the meeting or participated in it. The meeting was held in Buffalo, New York, November 15, 1955. The first and second meetings sponsored by Associated Industries were held in Schenectady, October, 1953, and in Rochester, November, 1954, respectively.

Two features of this conference make it somewhat unlike other technical meetings on industrial hygiene subjects. In the first place, like its predecessors, it was initiated and sponsored exclusively by an industry association. In the second place, most of the presentations were of the factory workshop variety, giving those in attendance a "ready to serve" noise reduction or attenuation application. While examples of successful noise reduction applications for a wide variety of noisy operations and short discussions of the basic ingredients of several operating ear protection programs commanded most of the conference time, the many unknowns and problems to which practical solutions are wanting were not overlooked. It is important that it be so, lest those reading the papers gain the impression that ready answers are available to all noise problems. Nothing could be farther from the truth. However, it is hoped that conferences such as this may constitute a source of positive rather than negative information to the end that the large number of unsolved problems slowly will give way to the growing library of tried and proved solutions.

That the Conference was eminently successful is evidenced by verbal and written comments received since the meeting.

—ALLEN D. BRANDT, Conference Chairman

Noise Reduction by Absorption, Shielding and Isolation

VAUGHN H. HILL
Engineering Service Division
E.I. du Pont de Nemours & Company
Wilmington, Delaware

WHILE noise reduction by sound absorbing materials is not the cure-all that many would like it to be, it does have a place in industrial noise control. It is hoped this discussion will help to identify its limitations, as well as its effectiveness. This discussion might seem quite elementary to many of you, but it is desired that all should understand the two problems to be discussed.

The amount of noise reduction which can be achieved by absorption in ceiling, wall, or hanging absorbers is relatively small when compared to the requirements of many industrial noise problems. Seven to 10 db is probably the maximum reduction that can be expected.

If the problem is one of protecting the hearing acuity of workers, the absorption treatment can be effective only if the following conditions exist:

(1) The room is reverberant, that is, has very little sound absorbing (soft, porous) material in it before treatment.

(2) The noise source is a multiple one,

that is, caused by many machines (perhaps six or more) and not by a single source.

(3) The noise production of any one source does not exceed the criteria, but the noise produced by the many sources does exceed the criteria.

An example of a condition which meets these requirements and for which sound absorbing materials were successfully used is as follows:

Room size—28′ x 50′ x 12′.

Room construction — Terrazzo floor, glazed tile walls, concrete ceiling (painted).

Machines in room — 50 small (¼ hp) punch presses; 80% of machines operated at any one time; machines operated at 800 strokes per minute punching holes in thin plastic tape.

Number of operators in room — average ten.

Special condition — sound absorption material must be dust-free.

Solution—

Absorption in room before treatment (at 512 cps) in sabins:

Ceiling 28 x 50 x .01	=	14.0
Floor 28 x 50 x .01	=	14.0
Walls (28+50) 2 x 12 x .03	=	57.0
Operator 10 x 4.2	=	42.0
Total A_1	=	127.0

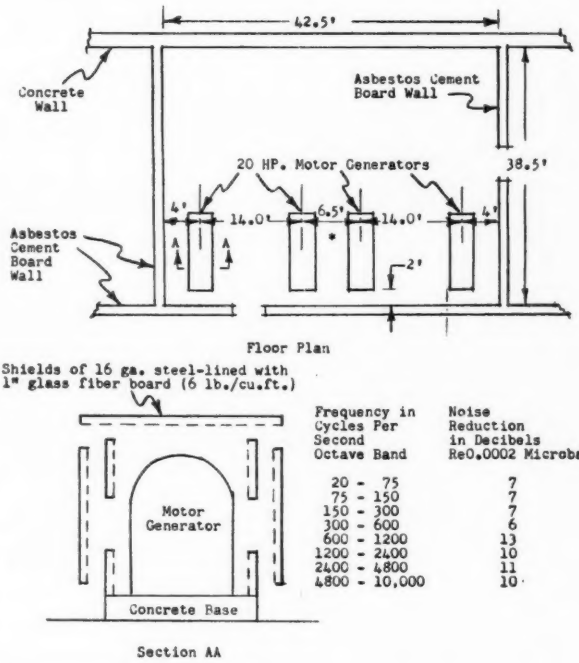
Absorption in room after treatment (at 512 cps) in sabins:

Same as above	=	127.0
Plus 312 hanging baffles at 7.4 sabins/baffle	=	2309.0
Total A_2	=	2436.0

$$\text{Noise reduction} = 10 \log_{10} \frac{A_2}{A_1} = 12.8 \text{ db}$$

at 512 cycles

Each noise absorbing baffle was made of glass fiberboard, 1½″ thick, 24″ wide and 48″ long having a density of 6 lb/cu ft. Each baffle was individually enclosed in a thin plastic film to prevent dusting. They were suspended vertically from the ceiling on wires stretched from side to side of the room. The wires held the baffles so that they



Frequency in Cycles Per Second Octave Band	Noise Reduction in Decibels Re0.0002 Microbar
20 - 75	7
75 - 150	7
150 - 300	7
300 - 600	6
600 - 1200	13
1200 - 2400	10
2400 - 4800	11
4800 - 10,000	10

Fig. 1.
Noise reduction by partial enclosure.

presented essentially an unbroken sheet with the bottom edge about seven feet above the floor and the top edge about one foot below the ceiling. The wires were located about three feet apart so that rows of baffles served to absorb the sound.

Actual measurements taken at operator's ear position when he was as close to machine as he would get during normal operation (12 inches) showed the noise reduction due to the baffles to be as follows:

Frequency in cycles per second (Octave band)*	Noise reduction in decibels— Re 0.0002 microbar
20 - 75	5
75 - 150	3
150 - 300	8
300 - 600	10
600 - 1200	7
1200 - 2400	9
2400 - 4800	9
4800 - 10,000	6

Note that the calculated value of 12.8 db of noise reduction at 512 cps was not achieved. In this case the 10 db was sufficient to meet the criteria so the installation was satisfactory.

Partial Enclosure

ANOTHER noise control measure of interest is the sound absorbing shield or partial enclosure. In a reverberant room having many sound sources such as usually exist in a manufacturing plant, the performance of such a treatment is difficult to predict. Results of an actual installation might help to show its possibilities.

The noise control problem is as follows:

Room size—42.5′ x 38.5′ x 18′ high.

Room construction—concrete floor, ceiling, and rear wall (unpainted); front and sidewalls—¼″ asbestos cement board on both sides of 2 x 4 studs; sidewalls (38.5′ side) extend from floor to within eight feet of ceiling.

Noise source—four 20 hp motor generator sets located as shown below.

There is other electrical equipment in the room but no other noise source or sound absorbing material of importance. The partial enclosure consisted of 16 ga. steel lined with 1″ of 6 lb per cu ft glass fiber board. Each end and the top of the partial enclosure was solid but the two sides were made up of three pieces on each side and staggered as shown to allow gravity circulation of air for cooling of the machine. It is to be noted that there is no direct path for a sound wave to escape from this partial enclosure; that is, any sound wave must strike an absorbing surface before it can escape into the room. This is an important feature if good performance is to be expected.

Performance of this partial enclosure is shown at lower right hand corner of Fig. 1. Sound level measurements were taken between the two machines and five feet above the floor. This location represented the maximum worker exposure.

This performance met the criteria and removed beyond recognition the piercing (rather narrow band) part of the noise.

Summary

NOISE reduction by absorption and partial enclosure is appreciable but limited when compared to the 20 or 30 db reduction required for many industrial noise control problems.

While the results of these two examples might not be exactly reproducible for your problems, they do indicate what might be expected.

Remember the three conditions that make noise reduction by absorbing materials effective for protection of the operator: (1) Room must be reverberant before treatment. (2) Noise source must be a multiple one. (3) Noise reduction required must not be too great.

Remember, also, that for noise absorbing shields, or partial enclosures, best results can be obtained by designing the shield so that the sound wave must strike a sound absorbing surface at least once before it can escape into the working area.

Noise Reduction at the Source

W. F. SCHOLTZ, Supervisor
Industrial Hygiene Department
Allis-Chalmers Manufacturing Company
Milwaukee, Wisconsin

THIS is the story of Allis-Chalmers' approach to one of the most important problems facing industry today—noise. The old attitude toward complaints by workers of excessive noise on the job was to tell them that they would get used to it after a few days. Many workers did get used to noise on the job, but only after they lost their ability to hear.

Our Company decided sometime ago that industrial noise was a problem that could be solved. Instead of looking for a cure-all that would work in the case of every noise problem, we have tried to apply common sense applications that have required no special knowledge other than a grasp of the fundamentals of physics which are involved. The following cases are specific examples.

A noise problem that was the source of numerous complaints was the exhaust from air vises (Fig. 1). By installing mufflers, a reduction from 94 to 79 decibels was achieved. The muffler is approximately two inches wide by eight inches long, and is filled with coarse steel wool.

A reduction from 95 to 85 decibels was

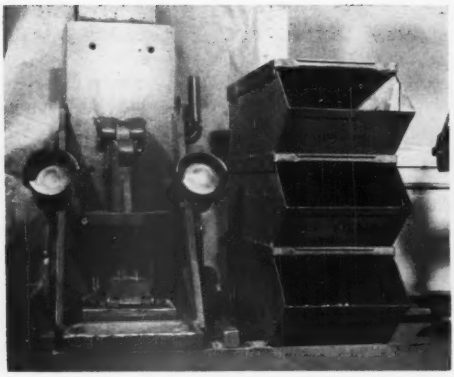


Fig. 1.
A muffler on the exhaust outlet of an air vise.

Fig. 2.
The bar stock tubes on an automatic screw machine wrapped with asphalt impregnated canvas duck.

achieved by wrapping bar stock tubes on an automatic screw machine with asphalt impregnated canvas duck (Fig. 2). This is the same material normally used to keep water pipes from sweating. We also installed coil springs inside the bar stock tubes and a similar sound level reduction was noted.

It is often necessary to do grinding and chipping on speed rings for hydraulic turbines. These rings are approximately 30 feet in diameter and 14 feet high. By placing sand bags on their lower ledges, we have reduced the noise level from 104 to 97 decibels.

In our plating room (Fig. 3), where we are exhausting approximately 40,000 cubic feet of air per minute from the area, an intense roar was caused by air rushing through the exhaust system. We coated the exhaust system plenum chambers and ducts with a chemically-resistant asphalt material. This reduced the noise level from 92 to 86 decibels.

The shakeout hood on a production molding unit was enclosed by placing a heavy canvas apron across the front opening where the man stands and enclosing the sides with appropriate material. This produced a six decibel noise reduction.

Our foundry cleaning room now contains wood instead of metal benches for holding castings which are in the process of being cleaned. The noise level was reduced five decibels when the wooden benches replaced the metal ones.

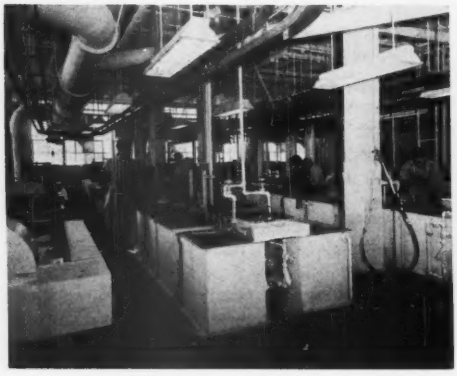


Fig. 3.
The plating room.

Fig. 4.
An acoustically treated office.

Not all noise abatement work ends in success. An office (Fig. 4) was acoustically treated in spite of our objections. It cost approximately $600.00 to place acoustical materials on the walls. The sound level reduction could hardly be measured. This points out that the indiscriminate use of acoustical materials does not necessarily bring about the desired results. In this case the problem was one of noise transmission through thin office partitions, not one of reverberation within the room.

Our tabulating room (Fig. 5) had a high noise level. After acoustically treating (Fig. 6) the walls and ceiling of this room, the overall noise level was reduced 10 decibels.

On several production operations where compressed air was used to either blow chips or to operate air grinders, we reduced the overall noise level by as much as 12 decibels when performing the operation in a small acoustically lined cubicle as shown in Fig. 7.

At our mass spectrograph (Fig. 8) we had a problem with high frequency noise. By lining the inside of the cabinet with heavy felt padding and by placing sound absorbers above the machine, the noise level in the room was lowered from 94 to 70 decibels, a remarkable reduction at very low cost.

The remaining noise abatement measures were applied in our La Crosse Works foundry cleaning room. This room is 70 feet long by 40 feet wide with a single saw tooth roof coming to a peak 30 feet above the

Fig. 5.
The tabulating room before acoustical treatment.

Fig. 6.
The tabulating room after acoustical treatment.

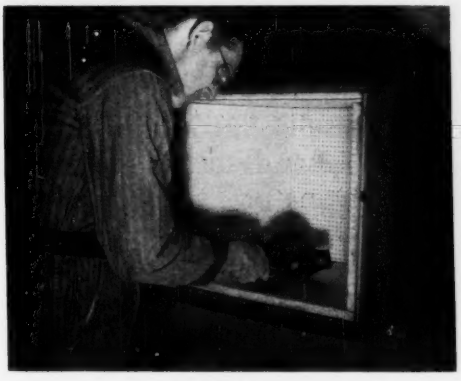


Fig. 7.
A grinding operation being performed in a small cubicle lined with acoustical board.

Fig. 8.
The mass spectrograph after acoustical treatment.

Fig. 9.
Stationary grinders.

Fig. 10.
The tumble barrel coated with mastic safety barrier raised.

floor. The floor is concrete with wood blocks, the walls are brick and tile, and the ceiling has asbestos tile of the block type.

By designing a steadyrest for the stationary grinders, a reduction of five decibels was achieved. The steadyrest sets on an asphalt impregnated material. Between each of the metal parts, a layer of asphalt-treated material was placed so that at no time is there direct metal to metal contact. (Fig. 9).

A wheelabrator hopper was coated on the outside with a mastic material the same as that used for the undercoating of automobiles. The thickness of the mastic was approximately ¼ inch. A wood liner covered with sheet metal was placed on the inside. This reduced the noise level approximately eight decibels.

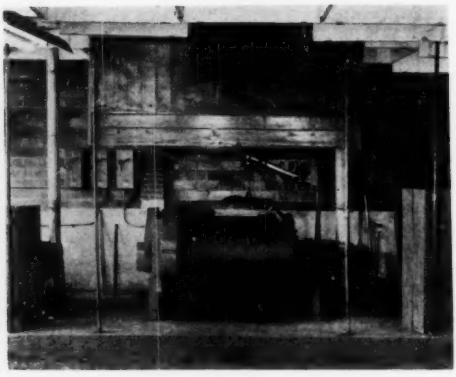


Fig. 11.
Overhead acoustic baffles.

By coating the tumblebarrels (Fig. 10) and the wood safety barriers in front of them with mastic, a reduction from 104 to 98 decibels was achieved.

Overhead baffles were also placed in the cleaning room, (Fig. 11). These baffles consist of spun glass fibers lined with a plastic sheeting. They were approximately two feet by four feet. They were hung from the ceiling approximately eight feet above the floor.

The combination of treating the noise producing machines and suspending baffles from the ceiling caused an overall noise level reduction from 106 to 91 decibels. The total cost for noise abatement in this foundry cleaning room was approximately $1,500.00 for materials and $1,000.00 for labor.

This is just the beginning of noise abatement work at our Company. It has proven to us that sometimes the simple applications to noise problems pay big dividends.

Noise Reduction on a Large Gear Reducer by Use of a Resonator-Type Enclosure

JOHN J. MEYERS, Chemical Engineer
Eastman Kodak Company
Rochester, New York

A SOUND measurement survey made at the Eastman Kodak Company showed that a total sound level of 96 db, measured approximately six feet from the source, was being generated at a paper calendering ma-

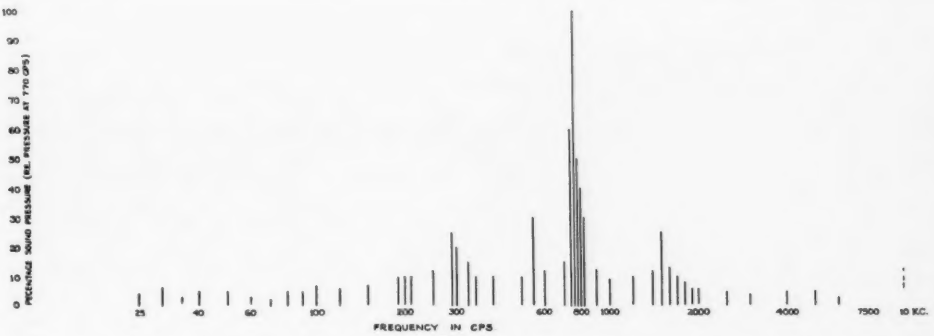


Fig. 1.
Sharp band frequency analysis six feet from gear reducer.

chine. Since several people worked in the area, it was decided to reduce the noise from this equipment.

An investigation showed the majority of sound energy was originating from the 200 hp gear reducer used to drive this calendering machine. Following an analysis of the problem, it was decided the most effective and economical method for reducing the noise level would be by means of an enclosure of the gear reducer.

It is necessary to provide the required sound energy reduction either by means of tight fitting, massive walls or by the use of lighter walls which utilize certain unique wall construction principles. Previous exploratory work on similar projects had shown that an extremely simple, effective, and economical sound attenuating structure could be obtained by employing the use of so-called "Helmholtz Resonators," particularly if the noise occurred at essentially one definite frequency. This was the case with the gear reducer in question since Sharp Band Analysis test data (see Fig. 1) showed that the majority of sound energy occurred at the specific frequency of 770 cps. Therefore, it was decided to adopt a "Resonator-Type Enclosure" for the gear reducer.

A "Helmholtz Resonator" consists of a rigid cell or enclosure of definite volume, equipped with one or more small openings (or necks) of both definite length and area. A disturbance of the air outside a resonator's neck will cause the air mass within the neck to vibrate (back and forth) in the same manner that a weight, which is attached to a spring, will vibrate when the system has been disturbed. The frequency of this vibration depends upon the volume of the cell and

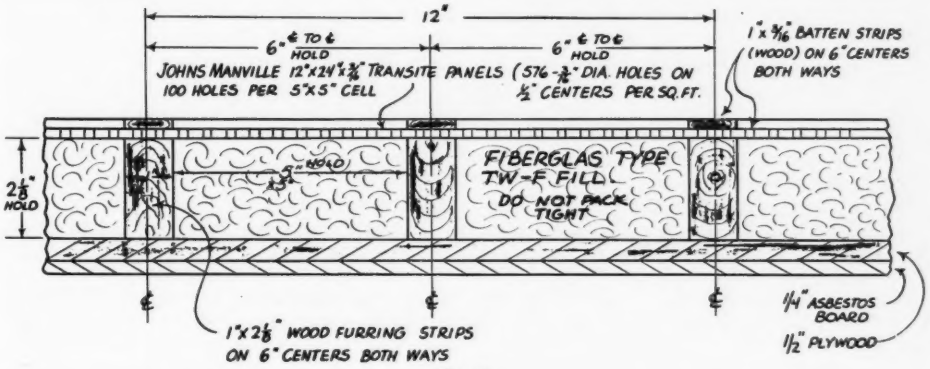

12"
6" ℄ TO ℄ HOLD
6" ℄ TO ℄ HOLD
JOHNS MANVILLE 12"x24"x3/4" TRANSITE PANELS (576-1/2" DIA. HOLES ON 1/2" CENTERS PER SQ. FT.
100 HOLES PER 5"X5" CELL
1"x3/16" BATTEN STRIPS (WOOD) ON 6" CENTERS BOTH WAYS
2 1/2" HOLD
3" HOLD
FIBERGLAS TYPE TW-F FILL DO NOT PACK TIGHT
1/4" ASBESTOS BOARD
1/2" PLYWOOD
1"x2 1/8" WOOD FURRING STRIPS ON 6" CENTERS BOTH WAYS

Fig. 2.
General details of construction for resonator-type sound enclosure used on gear reducer.

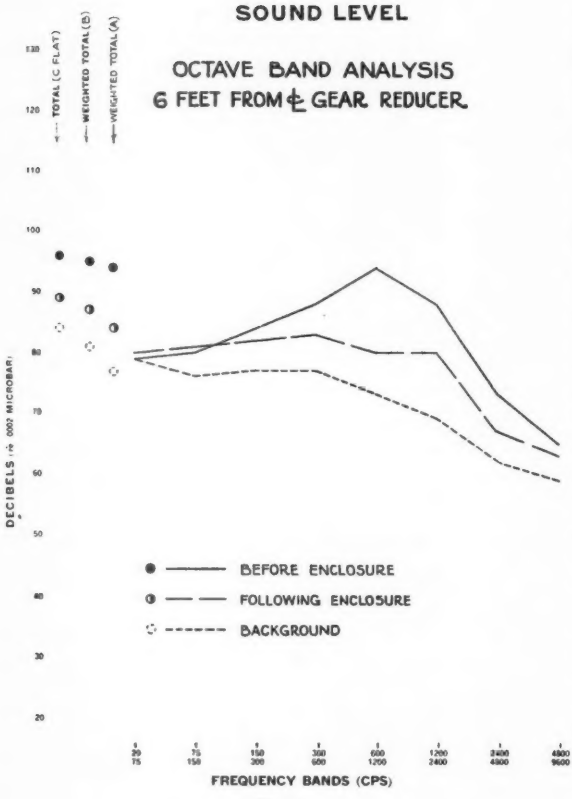


Fig. 3.

the length and total area of the neck (or necks).

With these facts in mind, the actual mechanics involved in attenuating an incident sound wave by means of a resonator can be described in the following manner:

(1) The incident sound wave creates the disturbance necessary to cause vibration of the air mass within the resonator's neck.

(2) This vibration within the resonator neck acts to reduce the incident sound energy in two ways: (a) It absorbs energy in the form of friction both within the neck and near the entrance to the neck. (b) It acts as a second source of energy which is reflected back toward the source. It is this second fact which makes resonators particularly effective for attenuating sound energy, since by designing the resonator so that it will vibrate (or resonate) at the same frequency as the incident wave will result in producing a reflected wave so phased as to both buck and diffuse the oncoming incident waves.

In accordance with these principles, the enclosure, used to cover the gear reducer, employed the use of many "Helmholtz Resonators" each designed to have maximum effectiveness at a frequency of 770 cps. The entire surface of each wall, used to form the enclosure, was composed of a multiplicity of rigid cells (or resonators) each constructed as shown in cross section by Fig. 2. The procedure for computing this cell (or resonator design appears in the Appendix of this article. It should be noted that all calculated cell dimensions and other design features were strictly adhered to during fabrication. Further, the structure is fabricated in several sections, held together by means of hasps, so that it can be easily disassembled.

The results obtained with this relatively light weight enclosure are very encouraging. The total noise level measured approximately six feet from the source was reduced from 96 db to 89 db, a reduction of 7 db. It should also be mentioned that readings taken at a second point of different orientation showed a reduction of approximately 12 db. Furthermore, the Octave Band Analysis test (see Fig. 3) made both with and without the enclosure shows a reduction of approximately 14 db in the 600 to 1200 cps frequency band. Of particular interest is the significant dip shown in the sound level curve between the 300 to 600 cps and 1200 to 2400 cps bands. This may be accounted for by the resonators.

In conclusion, the following comprises a list of some advantages observed with "Resonator-Type Enclosures":

(1) They result in providing sound level reductions at the specific design frequency and are reasonably effective over a frequency range of several octaves in addition to the resonate frequency.

(2) They are effective at all frequencies, particularly at the lower frequencies where most acoustical materials show low acoustical absorption characteristics.

(3) A structure is obtained which can be easily assembled and disassembled—a very important requirement when used on most mechanical equipment.

(4) The structure is easily fabricated and is reasonable in cost.

(5) The structure is fairly light weight.

(6) The structure can usually be fabricated from readily obtainable commercial materials.

References

1. ZWIKKER, C., and KOSTEN, C. W.: Sound Absorbing Materials. Elsevier Publishing Company, Inc., 1949.
2. KINSLER, L. E., and FREY, A. R.: Fundamentals of Acoustics. John Wiley & Sons, Inc., New York, 1950.

Appendix

INSPECTION of Fig. 1 (Sharp Band Analysis) shows that the majority of sound energy occurs at a specific frequency of 770 cps and that the frequency range from 300 cps to 1500 cps accounts for practically all of the sound energy. Therefore, design the resonator structure to have a resonate frequency of 770 cps and a reasonably effective sound attenuating selectivity range from 300 cps to 1500 cps.

For perforated panels, placed before a rigid wall, C. Zwikker and C. W. Kosten show the following relationships apply for resonators which show maximum absorption at the resonate frequency and about 50% of this maximum value at two other critical frequencies which define the effective width of the resonator's absorption characteristics.

$$f - \frac{1}{f} = \pm n\sqrt{gv}\,(u+1) = \pm \frac{GL}{6.28}(u+1) \qquad (1)$$

$$A_{res} = \frac{4u}{(1+u)^2} \qquad (2)$$

$$f = \frac{f_x}{f_{res}} \qquad (3)$$

Using these equations, first calculate the value required for (GL) which will provide a resonate absorbing 100% (i.e., $A_{res} = 1$) at 770 cps and 50% or 0.5 A_{res} at both 300 cps and 1500 cps.

From equation (2) when $A_{res} = 1$

$u = 1$

SYMBOLS

- A_{res} = percent absorption at resonance
- a = $0.785d^2$ = area per perforation (ft^2) or area per resonator neck (ft^2)
- C = velocity of sound in air at 100°F = 1150 ft/sec
- d = diameter per perforation (ft) or diameter per resonator neck (ft)
- f = ratio f_x/f_{res}
- f_x = any critical frequency (cps)
- f_1 = critical frequency (cps) below f_{res} at which absorption = $0.5A_{res}$
- f_2 = critical frequency (cps) above f_{res} at which absorption = $0.5A_{res}$
- f_{res} = resonate frequency (cps)
- G = $ng = (3.95\ (\pi)^2(V/L^2) = (3.95)(\pi)^2(S/L^2)$ = total conductivity per resonator cell ($ft.^{-1}$)
- g = $a/T = G/n$ = conductivity per perforation or per resonator neck (ft^{-1})
- h = porosity of porous material inside resonator cell
- k = structure factor for porous material inside resonator cell
- k/h = approx. (2) for most filling materials like fiberglas, etc.
- L = C/f_{res} = wave length of sound at resonate frequency (ft)
- n = number of perforations per square foot of cell area or number resonator necks per square foot of cell area.
- R = 3.33 log f_2/f_1 = width of frequency range (octaves) over which resonator absorption is equal to $0.5A_{res}$ or greater
- S = $V = (C/2\cdot\pi\cdot f_{res})^2 G$ = cell depth (ft)
- T = $t + 0.4(1 + k/h)d$ = equivalent length of neck for filled resonator (ft)
- t = panel thickness (ft) or length of resonator necks (ft)
- u = ratio of resistance of resonator/radiation resistance at resonance
- V = $nv = (1')(1')(S) = S$ = total cell volume (ft^3 per sq ft of cell area
- v = V/n = cell volume (ft^3) per perforation or cell volume (ft^3) per resonator neck

Next use a trial and error solution to solve for the necessary value of (GL) in equation (1) required to cover the frequency range 300 cps to 1500 cps when

$A_{res} = 1$ and $u = 1$. Applying this procedure (GL) must = 6.6 as shown by the following calculations:

$$f - \frac{1}{f} = \pm \frac{GL}{6.28}(u + 1) = \pm \frac{6.6}{6.28}(1 + 1) = \pm 2.10$$

$$f^2 - 1 = \pm 2.10f$$

$f^2 + 2.10f - 1 = 0$ from which $f = 0.40$ (a)

$f^2 - 2.10f - 1 = 0$ from which $f = 2.50$ (b)

since $f = \frac{f_x}{f_{res}}$,

then $f_1 = (0.40)(770) = 308$ cps

$f_2 = (2.50)(770) = 1925$ cps

therefore, the actual range of selectivity provided = $R = 3.33 \log \frac{f_2}{f_1} R = 3.33 \log \frac{1925}{308} = 2.65$ octaves.

Now determine the actual perforated panel design required, using a commercially available panel if possible. Since the required value of GL = 6.6 and since $L = C/F_{res} = 1150/770 = 1.49$ ft., the panel conductivity value (G) necessary = $6.6/L = 6.6/1.49 = 4.4$/ft.

Assume the use of perforated transite and calculate the value of (G) for Johns Manville perforated transite (3.16" thick, with 576 -3/16" diameter holes per square foot), as follows:

$$G = ng \qquad (4)$$

If the resonator cell is filled with loosely packed absorptive material such as fiberglas, this will aid in broadening the frequency range over which the resonator is reasonably effective. For a filled resonator

$$g = \frac{a}{T} = \frac{a}{t + 0.4(1 + k/h)d} \qquad (5)$$

Substituting equation (5) into equation (4) and assuming the factor (k/h) for fiberglas as being (2)

$$G = ng = \frac{(0.785)(n)(d)^2}{t + 1.2d} = \frac{(0.785)(576)(0.0156)^2}{(0.0156) + (1.2)(0.0156)}$$

$$G = \frac{0.1105}{0.0343} = 3.22 \text{/ft per sq ft of cell area.}$$

As previously shown, the actual required (G) is 4.4/ft., however, using (G = 3.22/ft.)* and maintaining a selectivity range of 308 cps to 1925 cps, we can calculate both (u) and the actual amount of absorption at resonance (A_{res}) which will be provided by this commercially available material. Since it was shown that $(f - 1/f) = \pm 2.10$ when the frequency range of 308 cps to 1925 cps is covered, we can solve for the new (u) by means of equation (1) as follows:

$$\pm \frac{GL}{6.28}(u + 1) = \pm 2.1 \text{ or } u = \frac{(2.1)(6.28)}{GL} = 1$$

$$\text{new } u = \frac{(2.1)(6.28)}{(3.22)(1.49)} - 1 = 2.74 - 1 = 1.74$$

From equation (2), new $A_{res} = \frac{(4)(1.74)}{(1+1.74)^2}$

$$= \frac{6.98}{7.52} = 0.93 = 93\%$$

Since this is still a fairly high efficiency, the commercially available Johns Manville transite (G = 3.22/ft.) will be satisfactory.

All that remains now is to determine the required cell dimensions for a material which has a conductivity value (G) of 3.22/ft. The following equation which expresses resonate frequency in terms of the cell volume (V) and total conductivity (G) can be used for this purpose.

$$f_{res} = \frac{C}{2\pi}\sqrt{\frac{G}{V}} = \frac{C}{2\pi}\sqrt{\frac{G}{S}} \qquad (6)$$

$$S = V = \left[\frac{C}{2 \cdot \pi \cdot f_{res}}\right]^2 (G) = \left[\frac{1150}{2 \cdot \pi \cdot 770}\right]^2 (3.22)$$

$S = 0.180$ ft. = say $2\frac{1}{8}$ inches.

To prevent any reinforcement of sound energy within the resonator cells, all dimensions should be maintained less than $0.5L = (0.5)(1.43) = 0.715$ ft. = $8\frac{1}{2}$ inches.

---

*It should be noted that if the resonator were not filled with a porous material, then $g = \frac{a}{T} = \frac{a}{t + 0.8d}$

therefore $G = ng = \frac{0.785nd^2}{(t + 0.8d)} = \frac{(0.785)(576)(0.0156)^2}{(0.0156) + (0.8)(0.0156)} = \frac{0.1105}{0.0282} = 3.92$/ft.

Although this provides a value more nearly equal to the actual desired value, it is believed the benefits derived from a filling material in broadening the range of resonator effectiveness are more important than the small improvement, which would be gained in absorption efficiency at resonance, with the higher (GL) value.

Constructing a Class Room in a Noisy Area

M. C. SKINNER, Engineer
Eastman Kodak Company
Rochester, New York

THE PROBLEM in this instance was to provide an area suitable for the conduct of a training program in a very noisy building. Space was available in a room about 33 feet by 50 feet located near the center of the building on the second floor. The building frame was of structural steel with reinforced concrete floor slabs. The room was enclosed with masonry walls. Immediately below the area was a maintenance shop and above was a stock room. Adjoining areas were an office on one side, the upper portion of a turbine room on one side, and the upper portion of a boiler room on the other two sides.

Sound level measurements were made in the area before the construction of the room (Fig. 1). The upper line on the chart represents the initial conditions. Total sound pressure level was 86 db. In the speech interference range (600 to 4800 cps) the level was 62 db. There was discernable vibration in the slabs, walls, and building frame. All in all, it was a rather nasty area to quiet.

Fortunately, the whole area was not required for the training program, and it was decided to construct a room about twenty feet square isolated as far as practical from the building structure. The location, chosen because of layout considerations, was that corner adjacent to the turbine room on one side and the boiler room on the other side.

Two masonry walls were erected which, with the two existing walls, formed an enclosure (Fig. 2). Within this enclosure, a wood floor with sleepers supported on isolation devices was built. Sound isolation fill was installed between the sleepers. On this floor wood stud partitions were erected and wood joists were supported on the partitions. Two wall isolators were used at each corner to keep the inner structure from shifting

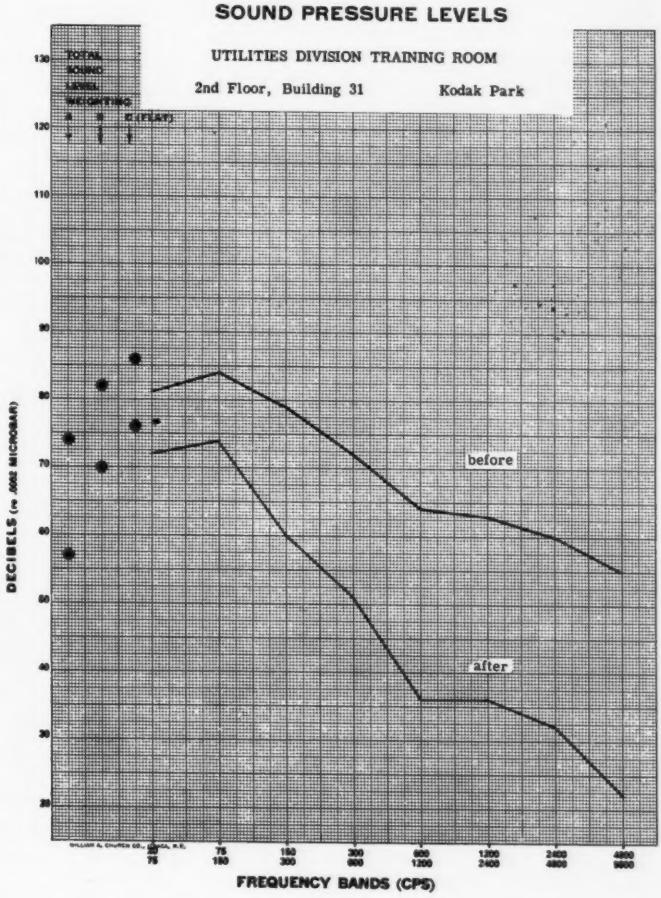


Fig. 1.
Sound levels before and after construction of sound isolated room.

within the masonry enclosure. Isolation blankets were installed on the masonry walls and on top of the joists. Walls and ceiling were then covered with plaster board. Perforated acoustical tile were cemented to the ceiling to provide absorption within the room, and the floor was covered with asphalt tile. Walls were painted after taping the joints in the plaster board. The door frame (Fig. 3) was attached to the inner structure and kept free from a metal buck frame in the masonry wall. A solid core wood door, fitted with weather stripping, was installed.

Supply air is brought into the room from

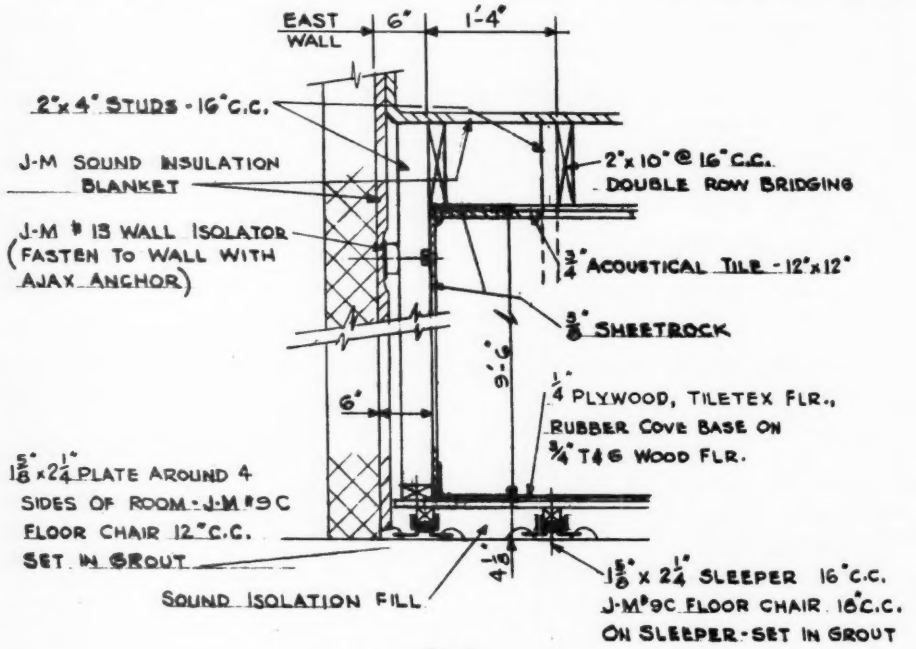

EAST WALL
6"
1'-4"
2"x 4" STUDS - 16" C.C.
J-M SOUND INSULATION BLANKET
J-M # 13 WALL ISOLATOR (FASTEN TO WALL WITH AJAX ANCHOR)
2"x 10" @ 16" C.C. DOUBLE ROW BRIDGING
3/4" ACOUSTICAL TILE - 12"x12"
5/8" SHEETROCK
9'-6"
6"
1/4" PLYWOOD, TILETEX FLR., RUBBER COVE BASE ON 3/4" T&G WOOD FLR.
1 5/8" x 2 1/4" PLATE AROUND 4 SIDES OF ROOM - J-M #9C FLOOR CHAIR 12" C.C. SET IN GROUT
4"
SOUND ISOLATION FILL
1 5/8" x 2 1/4" SLEEPER 16" C.C.
J-M #9C FLOOR CHAIR 16" C.C. ON SLEEPER - SET IN GROUT

Fig. 2.
Typical section of enclosure.

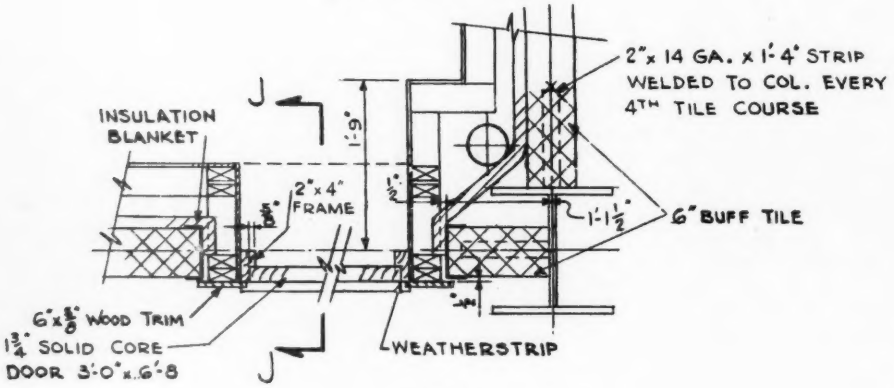


Fig. 3.
Detail at door.

a unit outside through diffusers in the ceiling. Duct work inside the enclosure is supported on the joists and connected to the outside ductwork with a flexible connection. Air is exhausted through grilles in the walls, the openings in the masonry wall being offset from those in the inner wall. Illumination is from recessed fluorescent fixtures.

This room within a room serves its purpose well. There is some slight vibration in the room, but one must look for it. The sound pressure level curves show the reduction obtained, though it is much more impressive to try conversation outside the room and then inside. Total sound pressure level was reduced 10 decibels from 86 to 76. Even in the lower frequencies there was close to a 10 db reduction (See Fig. 1). More impressive, and also more important, was the reduction of the speech interference level from 62 db to 35 db.

The idea of using sound studio techniques was the most obvious in this case, and appeared to be the most economical. The room is not up to sound studio standards, but it is adequate for its intended use.

Noise Reduction at Scrap Handling Tubs and at the Controls of a Scrap Baler

JACK C. RADCLIFFE
Supervisor of Industrial Hygiene
Ford Motor Company, Dearborn, Michigan

ATTENDANT to any steel stamping operation is the production of scrap pieces of steel. These vary in size from pieces four feet by four feet to small punched out holes less than an inch in diameter. Large pieces are usually further cut so that handling by belts, slat conveyors or scrap handling tubs is more readily managed.

In toting this scrap from the source to where it is baled, tubs on wheels are used (Fig. 1). These tubs are approximately 5′ x 6′3″. These tubs can be hooked together like a train with a tractor or small truck acting as the motive force. When these tubs are pulled over the normal wooden block floor, many small impacts develop at block joints with the production of rather high for the steel ones (Fig. 3).

noise levels. All of the tubs in question were originally equipped with steel wheels (Fig. 2). In an attempt to reduce this noise source, semi-hard rubber wheels were substituted

Fig. 1.
Scrap tub on wheels.

Fig. 2.
Steel wheel on scrap tub.

Fig. 3.
Rubber wheel on scrap tub.

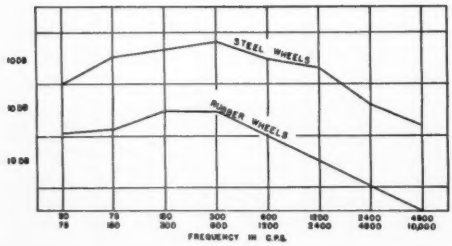


Fig. 4.
Noise spectrum with steel wheels and with rubber wheels.

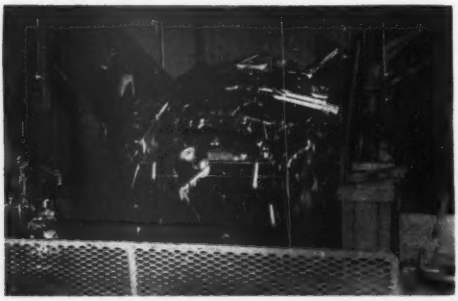


Fig. 5.
Scrap being fed into baling pit.

Fig. 6.
Baler operator's stand before enclosure.

Results shown (Fig. 4) indicate the reduction in noise levels when one steel-wheeled tub and one rubber-wheeled tub were pulled over the same wooden block floor area. Overall, a reduction of 12 decibels was attained. The greatest reduction was attained in the upper four frequencies, but some good was also evident in the lower ones.

In addition, to an economical means of noise control, it was calculated that there would be some savings in floor wear due to this change. Actual cost per wheel increases $2.70 when rubber is substituted for steel.

After scrap steel is collected it is brought by various means to one area of the plant for baling. Obviously, such scrap is of value and by baling it, a form is produced which is easily handled. In this operation, scrap steel on a slat conveyor is fed into a baling pit as shown (Fig. 5). The dropping of the scrap approximately six feet into the pit creates some noise. Attempts were made to line the pit, which has two movable walls, which act as the baler by compressing the scrap. This was found to be unsuccessful due to rapid deterioration of the lining. In addition, overhead space baffles were in-

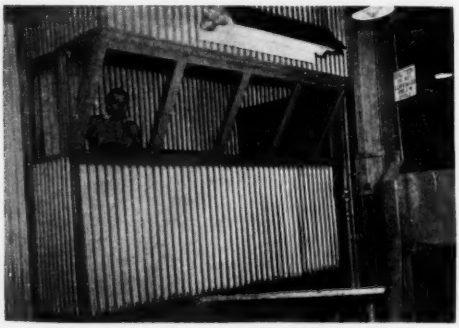


Fig. 7.
Baler operator's stand after enclosure.

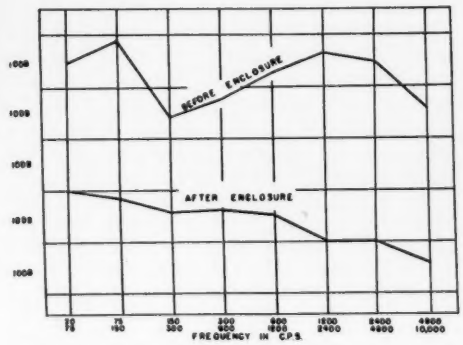


Fig. 8.
Noise spectrum before and after baler enclosure.

stalled, but they did very little good as far as the baler operator was concerned.

The baler operator is on a stand with controls approximately 15 feet from the point where the scrap drops into the baler pit. He operates the conveyor to drop the scrap, the baling machine, and the ejection equipment for moving the finished bale to a conveyor (Fig. 6).

As a final method of control, a complete enclosure was built for the baler operator and his controls. A double window was provided across the front for visibility and a small fan was installed for an air supply system (Fig. 7). Before and after readings indicate an overall reduction of 26 decibels (Fig. 8). Reductions were good all through eight bands with best results apparent in the upper four frequencies. This baler is rated as a ton unit.

Noise Reduction at Chipping Operations on Large Castings

JAMES H. BOTSFORD
Industrial Hygiene Engineer
Bethlehem Steel Company
Bethlehem, Pennsylvania

A NOISE problem existed in a shop where large marine propellers are manufactured and repaired. In the manufacturing process it is necessary to remove metal from the castings in cleaning, shaping and balancing operations. Most of the metal is removed by pneumatic chipping. In the case of a large propeller, several thousand pounds of metal must be removed altogether which requires several hundred hours of chipping. Many of the propellers are made of an alloy similar to bell bronze and produce a loud ringing sound during chipping.

A view of the propeller shop is shown in Fig. 1. The range of sizes and designs of propellers manufactured is shown by the assortment of propellers visible. The shop is necessarily an open area as shown, to permit the propellers to be moved about freely. An unfortunate consequence of this is that the noise produced by chipping on any one of the propellers spreads throughout the shop.

Several plans to reduce the noise at propeller chipping operations were tried. Wooden blocks and props were arranged to support the blades as firmly as possible. Steel weights and sand bags were used to weight down the blades. Each of these measures reduced the vibration of the blades somewhat and the noise which was generated by blade vibration, was reduced proportionately. Small sheds for housing a single propeller during chipping were constructed to isolate the noise; some were lined with sound absorbing material. A row of the chipping sheds is shown in Fig. 2. The propellers to be chipped are moved out of the propeller shop on small rail cars and transferred by crane to similar cars which carry them into the chipping sheds. A barrier is then placed in front of the shed to confine the chipping noise to the shed. These approaches will not be discussed further except to say that no combination of them

Fig. 1.
View of propeller shop.

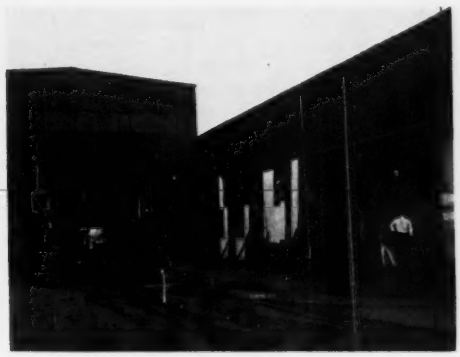


Fig. 2.
View of chipping sheds.

Fig. 3.
Vibration damping device.

Fig. 4.
Vibration damping clamps on propeller blade.

gave satisfactory noise reduction and each introduced new problems. The discussion will be limited to the vibration dampers which were developed and with which it is practical to reduce the ring of the propeller during chipping well below the noise of the chipping tool alone.

To many, the term vibration-damping means the prevention of transmission of vibration from one place to another as when a vibrating machine is placed on resilient springs or rubber mounts to reduce the vibration transmitted to the foundation. However, the vibration of the machine itself is not reduced when placed on resilient supports, but is actually greater than would be the case if the machine were attached firmly to the foundation. When the term damping is used properly, it refers to the reduction of vibration through the removal or absorption of the motional energy which is accomplished by the introduction of friction into the vibrating system in some way. With the vibration opposed by friction, the motional energy is quickly converted to heat and the vibration dissipated. A familiar example is the use of undercoating in automobiles which serves principally to damp the vibration of the thin metal panels.

The distinction between vibration isolation and vibration damping becomes clear when an automobile suspension system is considered. Springs are used to isolate the vibration of the wheels and axles from the frame and body. If springs only were used, however, the car would bounce incessantly and make driving difficult. To prevent this, shock absorbers are installed to present frictional resistance to the bouncing and to damp out these vibrations. In the case of the shock absorber, the frictional resistance is obtained by forcing a viscous liquid to flow through a stricture.

In the propeller shop, production requirements imposed certain restrictions on the vibration damping arrangements which could be used. The damping system had to be easily applied and removed leaving the surface of the propeller clean and unmarred. Moreover, the damping system would make large areas of the propeller inaccessible to chippers so that much time would be lost in moving the dampers as chipping progressed. It was also desirable that it be possible to attach the system to the propeller in such a way that there would be no danger of it falling off if the propeller were turned over or moved to a new position. These requirements were met by the device shown in Fig. 3.

The damper of Fig. 3 consists of two 6-inch steel disks ½ inch thick, one of which is welded to a bracket containing a screw to form a clamp having large bearing faces. The damping material is affixed to the inner faces of the steel disks and is pressed against the propeller surface when the clamp is attached to the blade. When the

blade vibrates, the heavy clamp does not follow the vibration of the blade because of its inertia and the resilience of the damping material, in this case, felt carpet padding. This differential motion of the clamp and blade causes a great deal of flexure and compression in the felt, and the resultant rubbing of the fibers converts the vibrational energy to heat. The use of the clamp assures greater flexure of the damping material than would be obtained if the felt alone were laid on the blade and as a result increases greatly the damping which can be obtained with a given amount of damping material. Also, the clamp arrangement fulfills the special requirements for a damping system mentioned above.

Actually, the felt shown in Fig. 3 provided insufficient damping and little noise reduction was obtained. Many other materials were tried and best results were obtained with an asphalt impregnated felt normally used as a damping material in automobile bodies, metal furniture, etc. This material was Type 401—62 lb industrial sheathing felt adhered with Type B 1340 Asphalt Adhesive, both of which are products of the Armstrong Cork Company, Lancaster, Pennsylvania.

Using this damping material, 50 dampers were made of an improved design; several of these are shown attached to a blade being chipped in Fig. 4. Two plates ½-inch thick and 6-inches square were welded to the jaws of a 6-inch C-Clamp. The square plates were simpler to make than the round ones and the use of the C-clamp produced a one-piece structure which is easy to handle. The chipping noise decreased as more dampers were used and was about the same as tool noise with six dampers per blade.

Through the use of vibration dampers, it was possible to reduce the noise at propeller chipping to a point where the chipping tool itself is responsible for the noise which remains. Admittedly, the propellers described are unusual castings; but, theoretically, there is no reason why vibration damping cannot provide equivalent results on any casting or assembly which produces considerable noise during chipping. A simple test will reveal those structures which can be quieted through vibration damping. If striking the structure which is ready to be chipped produces a ringing sound afterward, then the noise produced by chipping on that casting can be reduced by vibration damping. The longer a casting rings after being struck, the more noise it will produce during chipping and the greater the noise reduction which can be obtained through damping. An efficient damping system is necessary to reduce the ring during chipping below tool noise and considerable experimentation may be required to find the best method of obtaining such high damping in each case. When sufficient damping has been obtained, striking the casting will elicit only a dull thud.

There are probably many operations which can be quieted by vibration damping. Paradoxically, the very noisiest are likely to be the easiest to quiet. And what is more appealing, they may be discovered and the best means of damping developed with instrumentation limited to a hammer.

Reducing Impact Noise from Falling Parts

WALTER H. KONN, Research Staff
General Motors Corporation
Detroit

IMPACT NOISE from falling parts is widely encountered in industry. This discussion is confined to noise generated when metallic parts such as castings, forgings and heavy stampings fall on steel plates, chutes, hoppers, stock boxes or conveyors. The discussion does not cover the noise of such parts striking one another, as would occur when they fall into a partially filled stock box.

We believe that elimination at the source offers the greatest hope for control of such noise. In examining the problem from this standpoint we should first determine whether it is actually necessary to drop the parts from one level to another. One of our Divisions studied a process that involved parts falling from a washer into a chute. The parts were conveyed at a lower level and then raised to fall into steel hoppers. These parts were stampings 2½" x 3¼" x ½" weighing about a pound. The noise levels near these operations, measured with a sound level meter and octave band analyzer, are shown in Fig. 1. Note that the highest

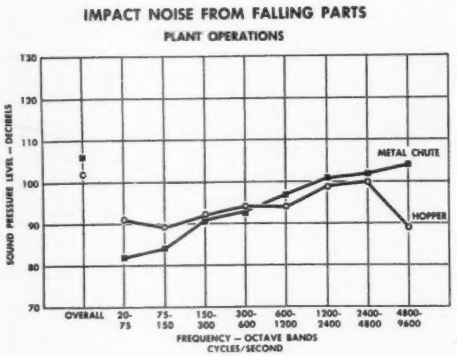


Fig. 1.

band levels are in the upper frequencies. The drop in the last band of the hopper noise is probably related to the fact that the parts are falling into a partially filled hopper and that impact noise of parts falling upon parts is being measured. After studying this operation it was decided that the first parts drop might be eliminated and the hoppers redesigned so that the parts would fall only a minimum distance. Self-leveling hoppers are under consideration to limit the final drop. You have probably seen similar devices in restaurants for keeping trays and dishes at a constant level. This installation is not yet completed, so we cannot give you noise reduction figures; but it shows that a critical study and ingenuity offer promise for control.

Rapid wear and cost are two big disadvantages in using rubber and wood linings to control noise from falling parts. Wear of rubber linings is related to the weight of the parts, the presence of sharp edges and the characteristics of the rubber. Some linings have worn out in a matter of a few weeks. Since the cost of lining an existing hopper 4 x 4 x 4 feet with ½-inch rubber was estimated at something like $150.00, this item could be appreciable where a number of hoppers are involved. Another factor which should be considered is safety. A falling part may hit a rubber lined hopper with sloping sides at just the right angle to be projected at a nearby employee. Wood linings have the disadvantages of splintering and becoming oil soaked and a fire hazard. They wear out rapidly unless fairly massive structures are used. For example, 4 x 4's about a foot long placed vertically in the bottom of the hopper or bin so that the parts fall on the ends of the wood may last a long time.

About two years ago it came to our attention that impact noise of the type described could be reduced by spotwelding a sheet of steel to the outside of the plate or hopper on which the parts fall. An over-all reduction of about 10 decibels is obtained with this laminated construction as compared with a single sheet. New hoppers embodying this construction can be made or existing units can be modified.

This hopper, made of ¼-inch boiler plate, is about 4 x 4 x 4 feet deep. Sharp, ringing noise was produced when a load of castings was dropped into it. It was modified by arc welding 16-gauge sheet steel to the outside

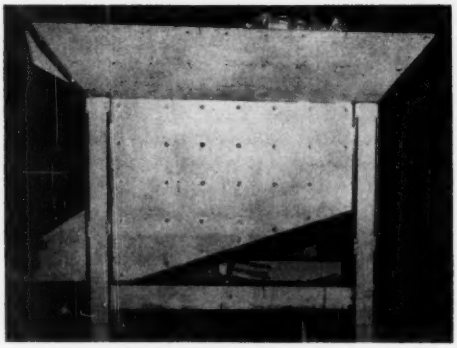


Fig. 2.
Hopper with steel plates attached.

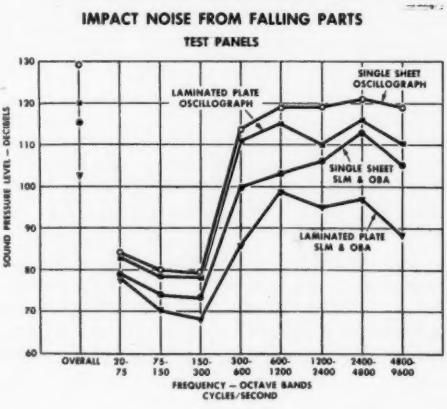


Fig. 3.

surface at about 8-inch centers. The sheet steel was drilled and the arc welds were made at the holes. Details of construction are in Fig. 2. Plates were clamped to the existing hopper and welded as shown. The cost was about $50.00, compared to $150.00 for lining with rubber. Overall reduction measured with a sound level meter was about 10 decibels. The sharp "ring" was greatly reduced and the noise was far less annoying.

Since this hopper was filled a comparatively small number of times daily, it was difficult and time consuming to attempt frequency analysis of the noise. Therefore resort was made to analysis on test panels in our laboratory. Single impact noise was produced by dropping a half-pound ball-bearing on the plates. The reduction measured on an oscillograph was nine decibels and most of this was in the bands above 600 cycles per second (Fig. 3). The reduction measured on the sound level meter was greater, but these measurements were given little credence because of the short duration of the single impact noise and the rapid swing of the needle. In the higher bands the frequency analyses show that this noise is similar to that for the chute and hopper described previously. These curves summarize the results of the measurements both with the oscillograph and with the meter and analyzer. They show that this inexpensive laminated metal type of construction yields about 10 decibels reduction and that most of this is in the high frequencies.

Noise Reduction at a Hammer Mill and at a Knife Cutter

RUSSELL S. HUNT, Industrial Hygienist
American Cyanamid Company
Bound Brook, New Jersey

WITH THE HOPE that our experience might be of value to some of you, I should like to present two instances where a reduction in noise level was accomplished. The first instance concerns noise from a hammer mill.

A hammer mill was recently installed which resulted in immediate complaints about the high pitched noise from the mill. The sound produced was similar to that of a siren. The rotor of the mill operated at 7000 rpm.

The mill is located on a platform suspended from the ceiling. Material is charged to a hopper feeding the mill from the floor above. The pulverized material is discharged from the mill to an air conveying system.

Noise level measurements indicated the noise level directly under the mill while grinding salt was 106 decibels. An analysis of the sound frequency distribution indicated that a high percentage of the sound pressure was concentrated in a narrow frequency range at about 1220 cycles per second. The decibel level and frequency gave us cause for concern.

Our first effort was directed toward reducing the speed of the mill. The V belt drive from the motor to the mill was changed to reduce the speed of the mill from 7000 to 4500 rpm. Operation at this speed was found to be feasible from the standpoint of production rate and the product desired. Further, we achieved a drop in decibel level to 96 decibels and the dominant frequency shifted from 1220 cycles per second to 930 cycles per second.

Although this was substantial improvement it was thought that an acoustic enclosure was required to further reduce the noise level. An acoustic enclosure consisting of ½" plywood lined with acoustic tile was installed to completely house the mill. Fig. 1 shows the exterior of the enclosure. The enclosure is provided with a door and is sufficiently large to permit maintenance

Fig. 1.
Hammer mill enclosure.

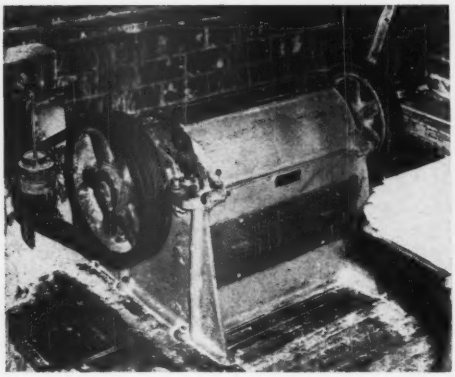


Fig. 2.
Rotary knife cutter without enclosure.

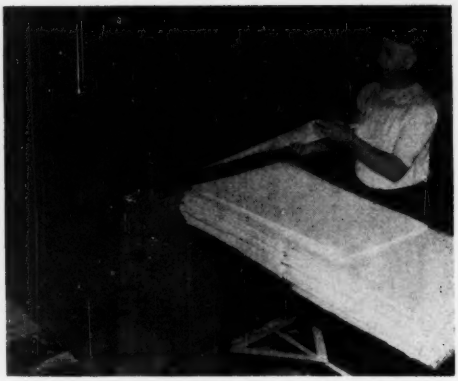


Fig. 3.
Enclosure for rotary knife cutter.

work on the equipment to be performed inside the enclosure.

Noise level measurements taken under the enclosure as before indicated the decibel level had now been reduced to 86 decibels. This represented an overall reduction of 20 decibels. The installation now offers no hazard from the standpoint of noise, at least judged by the criteria we now consider to be realistic.

The second instance concerns noise from a rotary knife cutter. Sheets of alpha cellulose paper, 30" square, are shredded in a rotary knife cutter. The cutting rotor of this machine is equipped with five knives which revolve at 900 rpm against fixed bed knives. The operator manually feeds sheets of the alpha cellulose paper into the feed slot of the cutter at the rate of approximately 30 sheets per minute. The shredded paper is discharged to a hopper beneath the machine on the floor below.

We found that the noise level at the operator's station adjacent to the machine averaged 110 decibels as the sheet of paper was fed through the cutter. A sound frequency analysis indicated that the predominant frequencies occurred in the lower and middle frequencies.

An acoustic enclosure consisting of ⅜" plywood lined with 1" thick sound insulation was built and installed. Fig. 2 shows the rotary knife cutter with the enclosure removed. Fig. 3 shows the enclosure and the operator feeding sheets of paper.

An opening in the enclosure approximately two inches wide was originally provided for feeding the sheets of paper into the machine. We found that the decibel level averaged 104 decibels at the operator's station. It was thought that noise produced internally in the machine was radiating from the feeding slot and through the opening in the acoustic enclosure.

The two-inch opening in the enclosure was modified. A chute from the enclosure to the feeding slot of the machine was made. This chute is approximately 8" long and ½" wide. It is lined with sound insulation protected by perforated sheet steel. Noise level measurements taken under similar conditions as before indicated the noise level now averaged 95 decibels. An over-all reduction of 15 decibels was therefore made.

A feature of this installation is the use of a chain hoist and trolley rail to remove the enclosure for maintenance work.

The installation of an automatic paper feeder is also under consideration by management. An automatic feeder would eliminate the necessity of an operator stationed at the machine. The acoustic enclosure would be retained to reduce noise in the area.

You will note, that in both the above cases, a stepwise approach to noise control was used. The hammer mill required first a reduction in speed and then an acoustic enclosure to effect a 20 decibel reduction in noise level. The original acoustic enclosure for the rotary knife cutter required alterations to the feeding slot to reduce the noise level 15 decibels.

An Approach to the Noise Problem in a Large Machine Shop

WILLIAM PRUESSMAN
Manager, Turbine Department
General Electric Company
Schenectady, New York

I HAVE BEEN asked to talk about an approach to the noise problem in a large machine shop. I appreciate the opportunity because I believe we are making some progress in reducing the noise level of operations in our shop.

In the audience today are two General Electric men who have played important parts in the progress we have made, and who have given me very valuable assistance. These men are Norman Sawyer, Acoustic Engineer, and John Ferry, Industrial Hygienist. Both have made many noise level measurements in my shop and have guided our noise reduction program.

As an introduction, I would like to give a brief description of the building with which we are concerned and the kind of operation performed in it. The building is 650 feet wide, 1400 feet long, with a million square feet of manufacturing floor area. Some 5,000 people are employed in this building on a three-shift basis. There are nine bays in the building extending from front to back.

I don't have the solution to the noise problem especially the kind of noise that is in between the low and the high levels. If people must be around a high level noise, our experience is that they will willingly use every kind of protective equipment. It is the in-between level of noise, (not loud enough that the workmen willingly wear ear protection, but loud enough to be potentially dangerous over a long term) that I believe requires further consideration.

One means of protection against noise is to wear ear plugs. In my opinion though, based upon our experience with other types of protective equipment, this is not necessarily an immediate answer to the noise problem even though at first it may appear to be.

I'd like to illustrate this point by our experience with safety glasses as I believe the protective value of safety glasses is more readily apparent. You can take safety glasses and bang them around, and we have a good many safety glasses that have saved eyes—yet, it has taken us a long time to sell our people on the wisdom of wearing safety glasses. Fig. 1 shows the trend of acceptance.

The wearing of safety shoes follows a similar curve, even though such shoes are a good buy and have prevented many an injury. I feel, therefore, that although we provide ear plugs free of charge to those who want them, to persuade a worker to wear ear protection is not an easy task, but one that requires—like the promotion of wearing safety glasses—constant education and persuasion.

The solution to the modern noise problem appears to be to try to lower the noise level

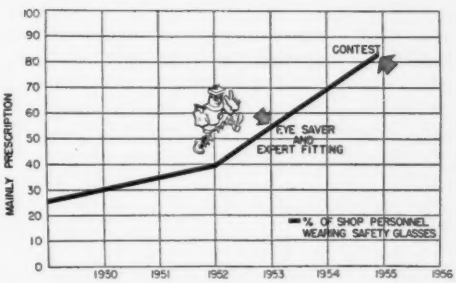


Fig. 1.
Percentage of shop personnel wearing safety glasses.

Fig. 2.
Pneumatic chipping on large castings.

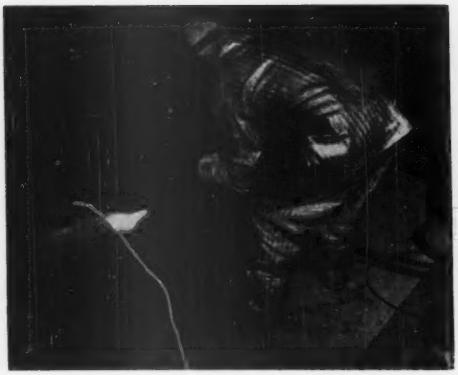


Fig. 3.
Flame gouging on large castings.

Fig. 4.
Pneumatic chipping on metal diaphragms.

by eliminating the noisier operations. First, how noisy is a noise? We expect to have some noise in the shop—if I don't hear any in mine, I know there is trouble. Also, on the other end of the scale, many times I have on a warm summer night been kept awake by the noise of a mosquito which certainly isn't very high on the decibel scale. So even a low level noise may be disturbing and perhaps should be eliminated.

The over-all noise level in our shop is within generally accepted limits and loud noises are usually of short duration, with two exceptions.

One of these exceptions is a chipping operation on large castings as shown in Fig. 2. I presume that except for the size and shape of the work piece, there are many shops doing similar work and encountering similar problems. In this area, we have tried various means of dampening the work piece by use of sandbags or blankets to keep them from ringing, but these means have not been effective. Changing from chipping to the more effective flame metal removing process eliminated this noise problem.

Fig. 3 shows a view of flame gouging operation which has supplanted chipping and removes metal much more efficiently. This has accomplished a noise reduction of approximately 20 db.

Fig. 4 shows the other noisy operation in which metal diaphragms are chipped with pneumatic hammers. As you can appreciate, it makes considerable noise. Again it was found we could more effectively remove the

Fig. 5.
High speed burring on metal diaphragms.

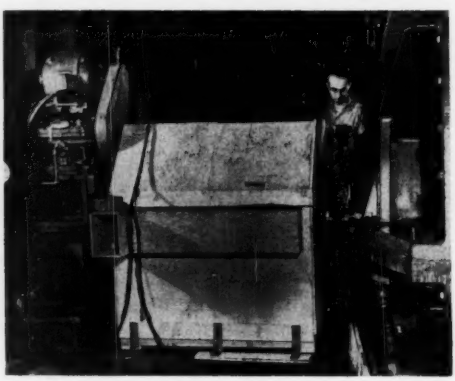


Fig. 6.
Enclosure at generator coupling.

metal by the use of high speed burrs in pneumatic grinders. The use of burrs as shown in Fig. 5 accomplishes appreciable reduction of noise level in this operation—in the order of 15 db.

A source of high level noise of short duration was a generator driven on test at operating speed by a 2500 horsepower motor. In this case the bolt holes in the coupling acted like a siren. We were able to design the cover or doghouse as shown in Fig. 6 to effectively muffle this high noise. The design of this doghouse incidentally was complicated by the windage loss which amounts to about five kilowatts. This amount of heat has to be dissipated from the box by circulating cooling air through properly designed passages.

Another successful reduction in noise was effected on a rotoclone when investigation showed that the duct work was vibrating too much. Vibration and noise were stopped by properly reinforcing the ducts.

As a further indication of what can be done to reduce noise, our study showed that at least a portion of the noise of the pneumatic grinder is caused by the exhaust of the grinder itself, and that this exhaust can be muffled. We found that the grinder manufacturers are willing to work with us in developing tools with lower noise levels. We are now specifying such levels on all new tools purchased.

The specifications which we require new tools to meet are as shown in Table I.

These specifications are compared with

TABLE I.
SOUND LEVEL REQUIREMENTS
Rotary Pneumatic Tools

Octave Band	Decibels
37-75	106
75-150	99
150-300	93
300-600	91
600-1200	90
1200-2400	90
2400-4800	90
4800-9600	90

The overall decibel rating is 96 when there is no noticeable peak on the B Network, and 94 if there is a noticeable frequency peak in the noise on the B network.

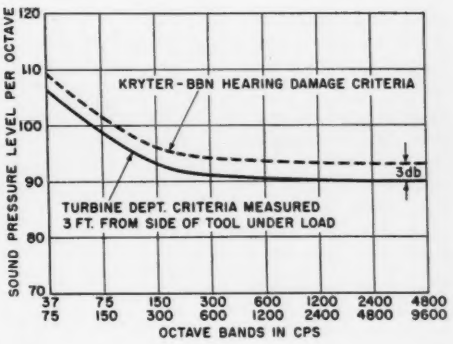


Fig. 7.
Noise limit for rotary air tools.

the hearing damage criteria as is shown in Fig. 7.

In summary, I have tried to show some of the problems encountered with noise in a large machine shop, and some possible solutions to such problems. I don't think the noise problem is an easy one to solve, either from the standpoint of reducing the noise or educating the workers to avail themselves of protective equipment. I do believe, however, that conditions can be made better than they are and that if we in industry try, we can make progress.

The Mechanics of an Industrial Hearing Conservation Program

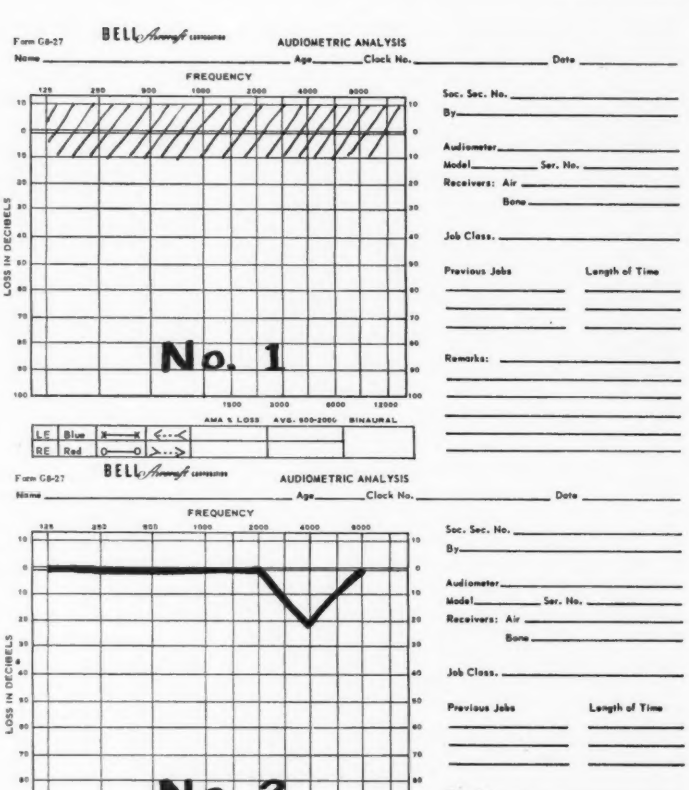
SEBASTIAN J. ROSICA, Consulting Audiologist
Bell Aircraft Corporation
Buffalo, New York

THE TERM "hearing conservation" is a relatively new one to industry. In the past it has been used primarily with reference to school children but today it has even greater meaning for industry.

Since hearing loss is primarily a medical problem, it is of concern to the plant Medical Director. In many instances the plant physician is not fully acquainted with the non-medical aspects of hearing conservation and must therefore call in experts in related fields such as engineering, audiology and acoustics. These experts in the related fields, then, comprise the "team" that will

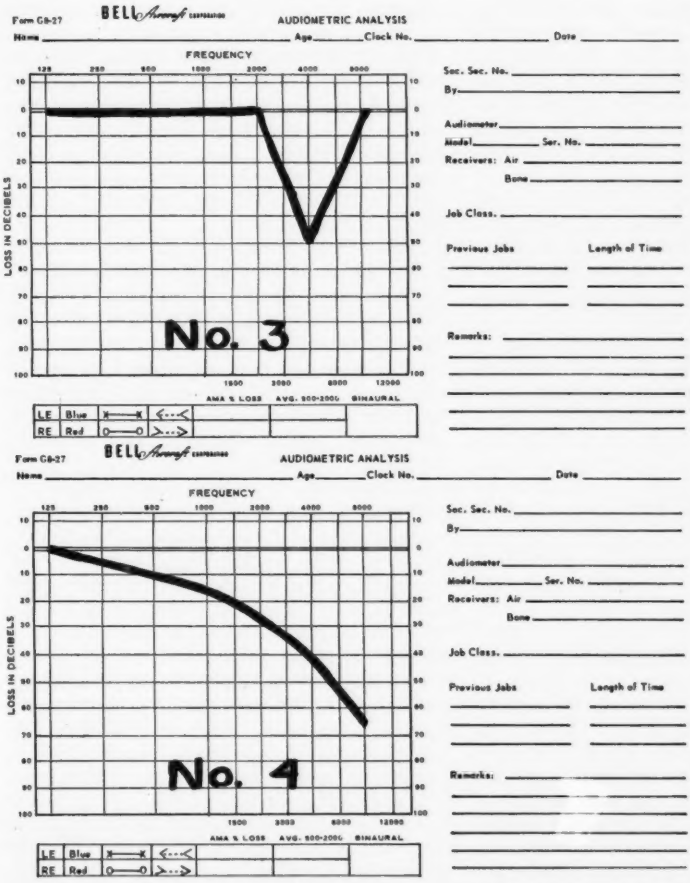
plan and carry out an industrial hearing conservation program. The problem of noise and its effect on the human ear is not one that can be adequately solved by the plant physician or the plant safety director. It is then a problem that is investigated by not one person, but a "team."

A hearing conservation program is exactly what the name implies, a means for conserving hearing. Although some may interpret this type of program as one which is primarily geared to benefit the worker, it nevertheless benefits management. Not only are the needs of workers investigated, but unjustified compensation claims against management are prevented. This leads to the first step in a hearing conservation program—that of pre-placement hearing testing. No physical examination of a prospective worker should be given without including a check on his hearing status. An accurate record of this should be filed in the man's medical file. This includes an audiometric test which can be rapidly administered by an industrial hygienist, audiologist or a nurse trained in the administration of such a test. A sweep-check screening is made of the frequencies 500 to 6000 cycles at a pre-determined intensity level. A quiet room away from noise and vibration may be adequate but a sound-proof enclosure is best. Failure on one or more of these frequencies demands a full audiometric check. Only air conduction testing should be used unless provisions are made for bone conduction tests and trained personnel are available to give and interpret them.



In order to avoid confusion, the employee's full name, clock number and social security number should be included on the audiogram. Clock numbers can often change but a social security number does not and provides positive identification. Included in this record is a history of previous noise exposure on other jobs. This information is invaluable when it comes to pin-pointing the type of job that may have caused an existing loss.

Together with pre-employment audiometric examinations, it is imperative that a complete noise survey be made throughout the plant, using both sound level meters and octave band analyzers. When interpreted in



terms of a suitable safety criterion, the results of such a survey will indicate from which plant areas employees should be re-tested within a given period of time to determine possible "sensitivity" to noise. Some individuals are more sensitive to noise than others and will show an early indication of acoustic trauma. At present, no test has been found which will adequately screen out those individuals who have "noise sensitive" ears. We must depend, therefore, entirely on the employee's re-test after he has been exposed to the noise environment on the job. Union-affiliated plants will find it desirable to give this re-test during the man's probationary period of work. Where a significant loss of hearing appears to be present in the re-test, management has recourse to two actions: (1) terminate the man's employment; or (2) change the man's type of job within the plant to one which is not hazardous, noise-wise.

Let us consider the second of these alternatives for there are times when a man is essential for a particular type of job and a replacement cannot be had. What can be done to safeguard his hearing? Three possibilities present themselves: (1) reduction of the noise at its source; (2) reduction of noise transmitted to the worker by interposing sound attenuating structures; or (3) supply adequate ear protection to personnel who must work in that particular area. Often it is necessary to use a combination of these approaches to obtain the required noise protection.

It is in (1) and (2) above that the engineers play a vital role. It may be possible to re-design machinery to reduce the noise, but this is rather costly and often impractical. Some other noise reduction measures which have been advocated are: (1) pressing or rolling instead of conventional forging; (2) belt drives instead of noise gears; (3) compression riveting instead of common pneumatic riveting; (4) welding instead of riveting; and many other possibilities.

The ideal solution of this noise problem would, of course, be the reduction of the noise at its source. Another approach is to reduce the noise reaching the worker in some way. Where these are impractical or unsatisfactory, the next step would be the

protection of the worker's ears themselves.

There are two basic types of ear protectors available to industry at the present time. They are the insert type of ear plug and the "muff" type of protector. There may be only slightly greater attenuation where a combination of insert and muff are employed.

In order to insure maximum efficiency and comfort in the use of individual ear plugs, a desired program should include the individual fitting of each employee. Most commercial ear insert plugs come in three or four basic sizes, and individual fitting insures more comfort and greater acceptance of the plug on the part of the employee. The industrial nurse could handle this phase of the program since each ear would have to be examined otoscopically for possible infection. While the employee is being fitted with ear protectors, the nurse should acquaint him with the mechanics of hearing and how it is affected by noise.

Thus far we have considered these aspects of the noise problem: (1) the control of the noise at its source; (2) the control of the surrounding area where noise is present; and (3) providing ear protection to the worker.

Let us now consider the interpretation of the audiometric tests which have been given both at the time of employment and the retest which is given after the employee has been exposed to the noise environment for a certain period of time. It must be understood, however, that these two tests are not the only tests given. Each worker in a noisy area should be tested periodically, preferably every six to 12 months.

AUDIOGRAM 1: Normal hearing lies roughly within 10 decibels above or below the audiometer zero reference level. Human hearing extends from approximately 20 cycles per second to about 20,000 cycles per second. For medical purposes, the range from 125 cycles per second to 8000 cycles per second is considered. In giving a screening test (which can be given to an individual in less than two minutes), positive responses at the 500 to 6000 frequency range indicates no hearing problem. It is imperative that the audiometer be used only by properly trained personnel. To insure accurate results and maintain test-retest reliability, the audiometer should be calibrated periodically, depending on the amount of use it has. A rapid method which is not too accurate but satisfactory to determine whether an audiometer is in need of factory calibration, is to have the person giving the hearing tests check his own hearing periodically.

What type of audiometric configuration, then, indicates the presence of acoustic trauma in a worker?

AUDIOGRAM 2: In nearly all cases of acoustic trauma, the loss is first evidenced by a notch in the audiogram in the 3000 to 6000 cycle frequency range. The greatest drop-off usually appears at 4000 cycles. When a worker who has had considerable noise exposure shows this type of loss, it is relatively safe to assume that incipient acoustic trauma is present. Generally, the individual experiences no difficulty in hearing speech. However, this loss progresses after continued exposure to noise.

AUDIOGRAM 3: The "notch" in the audiogram at 4000 cycles becomes more pronounced, both intensity-wise and frequency-wise. In this type of audiogram, the worker might begin to evidence difficulty in hearing higher-frequency sounds. If he is exposed for many years to noise of a high-intensity character, the "notch" might broaden and a general downward trend in the threshold may appear.

AUDIOGRAM 4: There is a noticeable problem in hearing speech and the worker might claim that some people "mumble" or do not "pronounce their words correctly." He will find it difficult to hear sounds in the higher frequencies such as bells, telephones and often a watch-tick cannot be heard.

If the worker continues in this noise environment for a number of years (an example is the classic "weaver's deafness") his speech may be affected. The speech range is roughly from 300 to 3000 cycles. When the threshold of hearing drops in the upper portion of this range, the consonant sounds are affected. He may not be able to pronounce certain words properly because he cannot hear the high-frequency components of those words.

Time does not permit going into the medico-legal aspects of hearing, but mention should be made of a test that should play a vital role in a compensation case, namely, that of speech-reception testing. We

should not be concerned primarily with an audiogram (where an individual listens for pure tones) but with that individual's ability to hear spoken language. How does this type of hearing loss which we call acoustic trauma actually affect the man's social adequacy? This is a field that is in need of serious consideration for the proper disposition of cases which are the result of exposure to noise.

You can readily understand, therefore, that this entire problem of noise and hearing is a most complex one—one that requires the services and understanding of both management and labor, of medical and non-medical experts in hearing, and of engineers (electrical and acoustical). We need the "team" approach to tackle this problem. It cannot be solved by theorizing from a platform, it must first be "sold to management," and then put into operation. Naturally, problems will arise where no solution is immediately available—a hearing conservation program does not always run smoothly. But if all concerned made it a point to clearly understand every facet of the program—both its possibilities and limitations—industry would be fulfilling its moral obligation to its employees, and protecting itself from unjustified compensation claims.

The Practical Aspects of Ear Protection

ARAM GLORIG, M.D., Director of Research
Research Center of the Subcommittee on Noise in Industry
Los Angeles

THE INTRODUCTION of protective devices into industrial situations is by no means new. The present day worker is acquainted with all manner of these gadgets to protect him from the soles of his feet to the top of his head. The modern worker resembles a man from Mars when he is equipped with his industrial protective armor. Early in the growth of industry, the hazards of production exacted a very large toll in the battle between men and machines, but little by little the battle has been won until, at present, the hazards of production cause relatively few casualties. Our discussion, however, concerns a relatively new addition to this armanent—one that has been needed for many years—ear protection.

Noise-induced hearing loss has been known since early in 1800, but it was not until World War II that concerted efforts were made to develop effective ear protection. The subject of ear protection has many theoretical aspects which have already been discussed before this group. It is my purpose to discuss some of the practical applications of ear protection programs.

Perhaps the external ear canal would be a good place to start. There are several things about the external canal that are important to ear protection. The shape of the external canal does not lend itself to an easy and good fit. It is curved in two directions, and funnel shaped in its external one-third to one-half, narrowing inwardly. The external one-third is formed of a continuation of cartilage from the external ear covered with skin and subcutaneous tissue. The skin contains sweat glands, wax glands, and hair follicles. As the skin continues inward it becomes thin and fragile where it covers the bony part of the canal until it reaches a circular ridge called the annulus to which the drumhead is attached.

The internal one-half of the canal becomes slightly larger toward the drumhead as it leaves the narrow part. The bottom part of the cartilaginous portion covers the joint of the lower jaw and moves inwardly with motions of the jaw.

The skin of the canal is quite sensitive but especially so where it covers the bony canal. As one looks into the canal, one can see an area of the posterior wall which appears to obstruct the canal. Further, when the external ear is pulled backward one can see a ridge of cartilage posteriorly which moves back and forth when the external ear is moved. Like all other biological measurements, ear canals vary widely in size and configuration. Not only from individual to individual, but even between ears on the same individual. I recount all this to explain some of the difficulties which are encountered in providing acceptable ear protection.

Perhaps a definition of ear protection, what we are trying to protect and protect against, is in order. Ideally, ear protection must include enough attenuation at each of the frequencies of the audible spectrum to

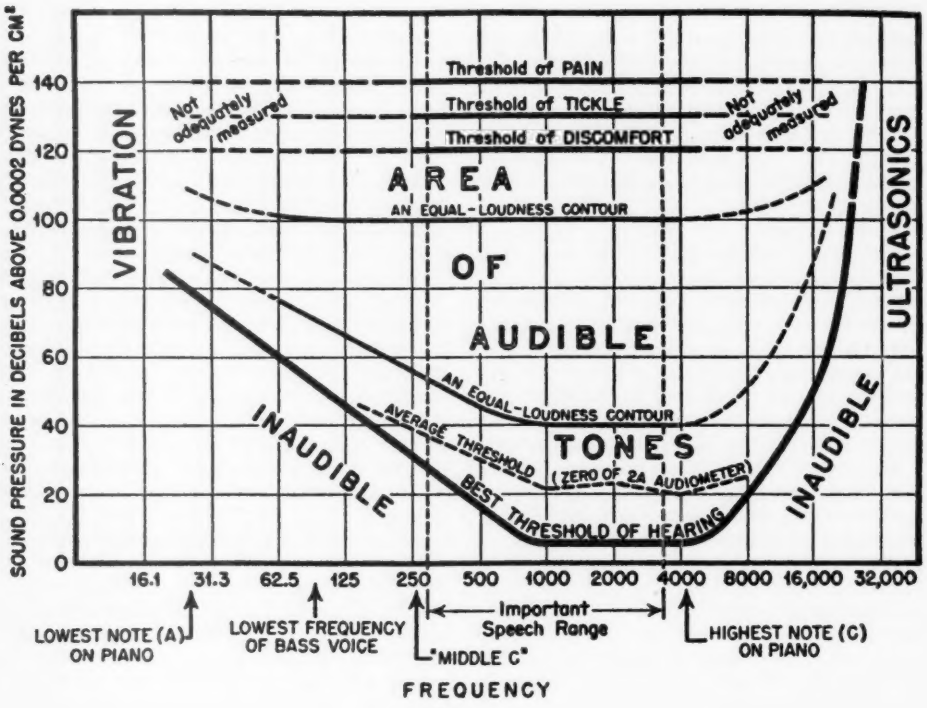


Fig. 1.
The auditory field.

prevent a hearing loss anywhere in the spectrum. Experience has taught us that such an ideal is impossible. Consequently, we must apply a limited definition to ear protection in terms of our concept of hearing loss or damage. If we accept the broad meaning of damage we are again confronted with the fact that we cannot prevent all damage, and must accept a limited meaning of this term.

If we assume that the most important area in the audible spectrum is the speech range, and I believe we must, we can define damage as injury to the frequencies between 300 and 3000 cps. With this concept in mind, we can measure the efficiency of ear protection in terms of attenuation in the frequencies which will produce a hearing loss in the speech range (Fig. 1.)

Laboratory studies with pure tones indicate that exposure to high level tones causes maximum hearing loss at frequencies about one-half to one octave above the exposure tone. The complex sounds found in industrial situations do not necessarily follow the same pattern, but temporary threshold shift studies indicate that complex industrial sounds usually cause larger threshold shifts above 1000 cps than below. Referring again to the speech range, we find that the injury usually occurs in the upper half of this range or the area where changes in threshold may be used as an index of damage. Now since most industrial sounds contain a large amount of energy below 1000 cps, it is reasonable to assume that the frequencies below 1000 cps are causally related to hearing loss in the speech range. In support of this, we note that most industrial losses occur above 1000 cps. Therefore, we may reason that the most significant measure of the efficiency of ear protection should be based upon the attenuation obtained between 300 and 1000 cps. I might add that if good attenuation is obtained in this area, in most cases, the higher

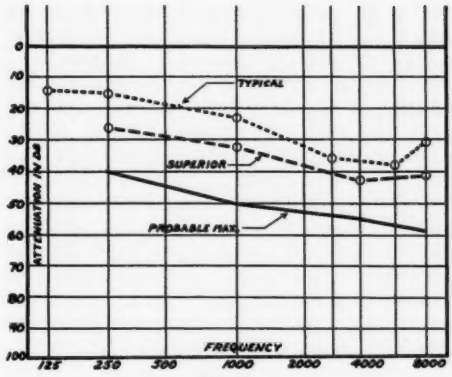


Fig. 2.
Attenuation accomplished by use of ear plugs.

frequencies will be adequately attenuated.

Now, how do we measure ear protection? The presently accepted method is based on free field pure tone measurements of the unoccluded ear as compared to the occluded ear. Remember, that these tests are conducted under laboratory conditions. The ear protectors are carefully fitted and maintained in place during the measurements. Whether or not the resulting figures can be directly transposed to the industrial situation is another matter. We feel that the laboratory conditions produce maximum attenuation figures and that in actual practice the amount of attenuation is slightly less. Just exactly how much less is difficult to say, probably 5 db would be a fair estimate. We have no valid data on this question at the present time. (Fig. 2).

In our study of the temporary threshold shift we have found an indirect means of measuring the effectiveness of ear protection in the industrial situation. The temporary threshold shift or TTS is that amount of change in the auditory threshold which occurs as a result of a specified exposure to industrial noise. When this shift is measured with and without ear protection the result is a measure of the protection afforded by the particular device in use. Obviously, this would be a cumbersome technique to adopt as a standard measure of ear protection, but it is a valuable means of deriving research data on the subject (Fig. 3).

Just how much attenuation or protection can we expect from plugs in the ear or muffs over the ear or even helmets over the entire head? Theoretically, one should be able to attenuate sounds carried to the mid-

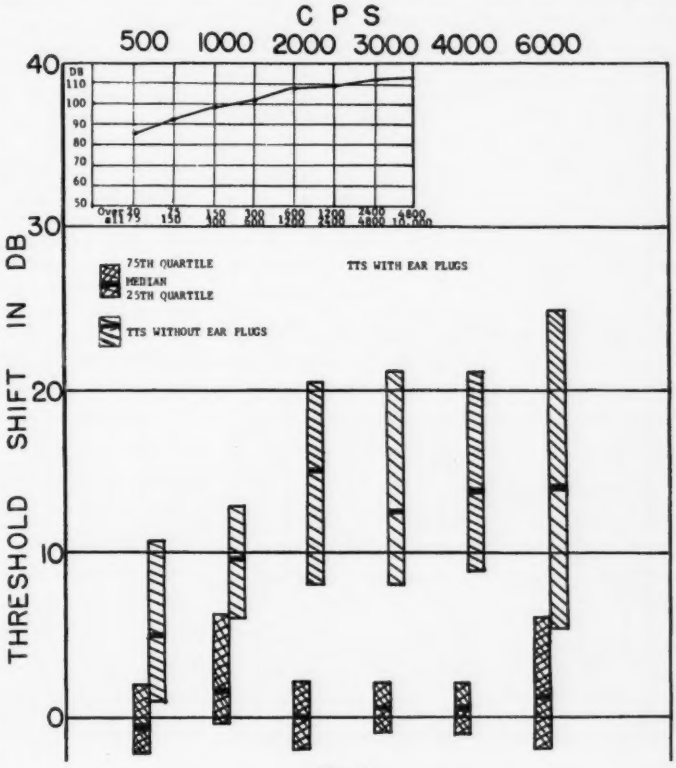


Fig. 3.
Temporary threshold shift with and without ear plugs.

dle ear by air conduction by placing an obstruction between the sound source and the ear. Further, one would expect that the amount of attenuation produced would vary with the material placed in this sound path. And that material which produced a certain amount of attenuation in vitro would do the same in vivo. Unfortunately, this is not true.

There are several factors which govern the amount of protection possible. First, the maximum amount possible by air conduction is about 50 db because as the sound pressure increases above this figure the energy is conducted to the ear by way of the bones of the skull, the skeletal bones and the body cavities (See Fig. 2). To date, no single ear protector or any combination of devices has succeeded in reaching the maximum figure. In general, in the laboratory one can expect to attain about 15-20 db below 1000 cps and 35-40 db above 1000 cps. The material used in the plug has no effect beyond this point, whether in the form of a plug or a muff. This difference between the maximum possible and maximum obtainable may be related to conduction via the skin covering the head, external ear and canal. We know that the 50 db maximum is fairly well fixed from studies of children with congenital absence of the external canal and middle ear. We also know that the normally closed Eustachian tube provides about 50 db of attenuation eliminating any possibility of a leak via the nose and throat. Many of you are wondering about helmets and perhaps, even so-called space helmets and logically so. If you will remember, however, I mentioned that sounds get to the ear via the skeletal bones and the body cavities. Even if the skull and face are completely covered down to the neck, the ear will be reached by way of the chest cavity, principally. Again, we find it impractical to reach the theoretical maximum.

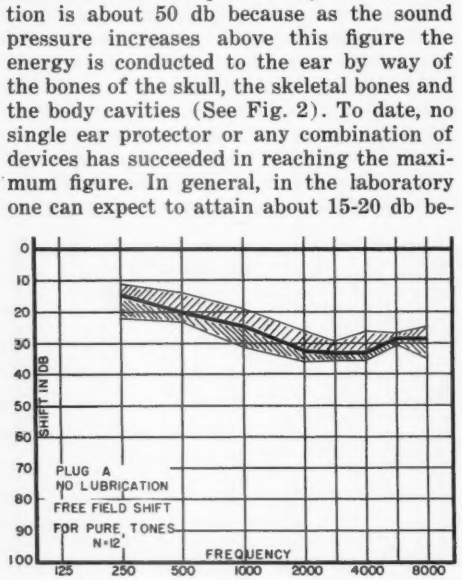


Fig. 4.
Attenuation accomplished by plug "A."

How much attenuation can we get? Most of the available devices will provide between 10-20 db below 1000 cps and 30-45 db above 1000 cps. Attenuation of the frequencies above 2000 cps is easy. Most anything that has any semblance of a tight seal will give good attenuation in the frequencies above 2000, and slightly less at 2000 cps, considerably less at 1000 cps, and only a relatively small amount below 1000 cps (Figs. 4-8).

Which plugs are the best? This is easy, those that are worn. There is no one "best" plug. Some plugs provide slightly more at-

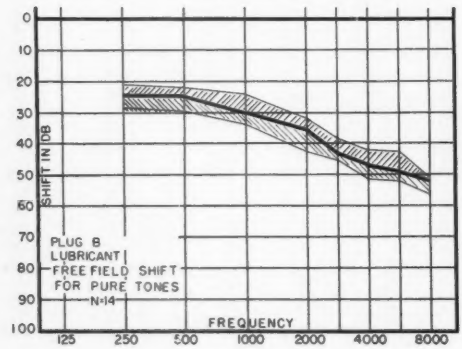


Fig. 5.
Attenuation accomplished by plug "B."

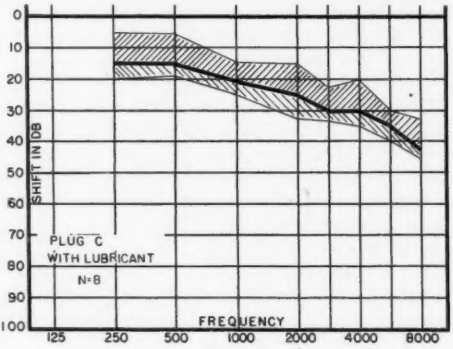


Fig. 6.
Attenuation accomplished by plug "C."

tenuation than others, but the differences among the four or five that have become generally used are very slight and unimportant when used in the majority of industrial situations.

What about the material used to fabricate the plugs? Any plugs that are made out of a semipliable material and provide a good seal with the least amount of discomfort are suitable. (It may sound facetious to say that the best plug is the one that is worn. Believe me, it is not. No matter how good an ear protector is, if it is not accepted by the worker, it is worthless.) Some plugs are made with metal or other hard inserts and fillers. I am against these because of the danger to the ear in case of blows or explosions. I know of one case where a metal filler was blown through the middle ear and skull into the inner ear because of an explosion. There is no gain in attenuation from these metal inserts. Other plugs are made with valve-like arrangements which are supposed to allow better hearing for speech. The valve is reputed to close against a seal in the presence of high level noise. Theoretically, this sounds good, but practically, it does not work. Still others recommend individually molded or custom made plugs. There are no advantages to these except in the individual with ears that cannot be fitted with prefabricated plugs.

What about wax impregnated cotton or gauze plugs? These provide just as much attenuation as any plug under laboratory conditions, but because of their consistency I do not believe they will maintain a good seal over long periods of time without continual readjustments. The wax has no resiliency and when the plug changes its position in situ there is no return to the original position, thus allowing for a continuous leak. I have seen cases where these plugs were merely put into the ear with no attempt to form a seal. Heat will soften them and break the seal, also. They cannot be kept clean, in fact, they must be renewed daily, and therefore, are expensive. Some will say that acceptance is better with wax impregnated plugs. I do not doubt this, but I believe it is due to the lack of pressure against the canal wall, and even though well accepted, does not maintain an optimum seal resulting in decreased attenuation in the practical situation.

In my experience, the plugs made of soft plastic, neoprene or rubber are, in general, better than those made of other materials. They are soft enough to conform to the ear canal and yet resilient enough to maintain a good seal.

How should ear protection be distributed? This is an extremely important part of an ear protection program. Experience has shown that the best way is through the medical office. The nurse or technician should fit each ear separately and choose the plug which fits tightly with only slight discomfort. Those plants which have no medical departments or medical personnel should have someone who has been trained to fit ear plugs, and made responsible for seeing that it is done properly and routinely. A loose plug is worse than no plug. While this is being done, the nurse or technician should explain the reasons for the fitting procedure.

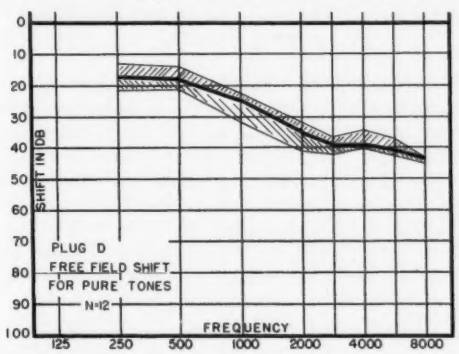


Fig. 7.
Attenuation accomplished by plug "D."

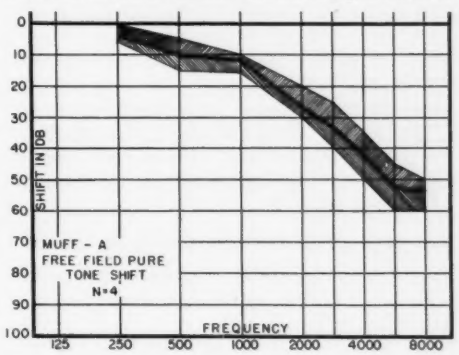


Fig. 8.
Attenuation accomplished by muff "A."

Emphasizing the fact that these plugs are personally fitted to the worker is always good. He must also be told that the best way to judge the efficacy of the plug is to adjust and readjust it until the noise sounds the least loud. This should be done several times daily. No distribution plan is complete unless there are at least three or four different makes of plugs available for fitting. A type that may be suitable for one man may be entirely unsatisfactory for another. Then too, when there is a choice available the worker feels he has more of a part in the program, and that everything possible is being done for him.

Are there any complications directly attributable to wearing ear protectors? This may be answered with a firm, "no," provided there is no existing pathology in the external or middle ear. The incidence of external otitis due to wearing ear plugs is negligible. There is no danger to the drumhead if the soft rubber-type plugs are used. None of the generally used plugs are long enough to reach the drumhead if properly fitted. The discomfort noticed at first is not damaging to the external ear. It is due to the slight pressure exerted by the resiliency of the plug and will disappear in a short time.

Do earplugs make it more difficult to hear speech and warning signals? Definitely not. In fact, these signals can be heard better when ear plugs are worn in continuous high level noise. It is very easy to demonstrate this. Merely put your fingers in your ears while in a continuous noise and listen to your neighbor. Remember, though, that you can hear your own voice much better and be sure to raise your voice when speaking in order to be certain you are not dropping it below the level necessary to override the ambient noise. Many times the workers will object to ear plugs because they are afraid speech and warning signals will not be heard. You may assure them that this is far from true.

Conclusions

1. The anatomical configuration of the ear canal makes individual fitting of ear plugs necessary.

2. The efficacy of ear protection is, perhaps, best assessed by the amount of protection afforded in speech range.

3. If we assume that the speech range is the most important part of the audible spectrum it is also reasonable to assume that the frequencies between 300-1000 cps are causally related to hearing loss in this range.

Lockheed's Ear Protection Program

J. F. HATTON, Chief Safety Engineer
Lockheed Aircraft Corporation
Burbank, California

IT MUST have been 10 or 12 years ago that Lockheed became cognizant of the noise problem associated with some of its manufacturing operations and began to do something about it.

Periodic audiograms on people exposed to excessive noise (100 db and above) were inaugurated at that time and a supply of ear plugs was obtained for free distribution to employees. Ear plugs were stocked in all of the Company's first aid units and Medical Department nurses were given the assignment to fit them individually.

The audiograms were taken by an outside contractor and not too much effort was made to sell the individual employee on the wisdom of wearing ear plugs at the time the audiograms were taken.

Word was passed along through line supervision that ear plugs were available and those employees who needed them were encouraged to obtain them.

After about six months, the contractor industrial hygienist, as a result of some study and tests, recommended we change the type of ear plugs being secured and this was done.

About 1947, the hearing conservation program was expanded to include pre-employment audiograms on new employees going into noisy occupations. Also at this time, the company dispensed with the contractor taking the periodic audiograms and assigned this activity, together with the new employee tests, to a capable registered nurse employee, under the guidance of a qualified M.D. (Fig. 1).

This audiogram technician was given instructions to take a minute or two immediately after an employee had been given an audiogram, and attempt to sell him on the

Fig. 1.
Measuring hearing at Lockheed.

wisdom of wearing ear plugs. It was felt that the employee at this particular time would be in good frame of mind to receive an ear plug sales talk. This subsequently proved to be the case and this audiogram technician, followed by her associates, did much to increase the number of ear plugs being worn by employees. It is the writer's opinion that this "person to person sales appeal" should be made a definite part of every audiogram technician's duties. It is well worth the little extra time that it takes.

Our experience has indicated that most factory people exposed to loud noise will wear ear plugs if they are made available—mostly, I think, because of comfort rather than any real fear of hearing loss. However, our experience has also shown that a sizeable minority (as much as 40%) will not wear them of their own volition. Their stock answer seemed to be "I've been doing this same kind of work for several years and nothing has happened to my hearing yet—besides, those darn things hurt my ears." These become the real problem people. Dispersed among these were some who deluded themselves by wearing dry cotton.

Well, as I said before, our audiogram technicians helped immensely in this problem. Additional pressure was put on line supervision to insist that ear plugs be worn where necessary—to do it on a positive rather than on a negative approach.

About that time, we began using some disposable cotton impregnated wax plugs. Employees took to them more readily and these alleviated some of the complaints about constant pressure against the ear canal by properly fitting resilient rubber plugs. Soon the majority of our people were using the wax plugs. Because they were expendable, they cost the Company more money. However, Lockheed was glad to absorb this additional expense since it resulted in more widespread protection.

Some employees still resisted, feeling that noise did not bother them. Supervisors were told that when other accepted means had failed, as a last resort those employees refusing to wear ear plugs should be disciplined, i.e., the same as refusing to wear safety glasses when needed. A written notice of criticism, followed, if necessary, by a few days off, is the accepted method.

At the present time, we are happy to report that a large majority of our people on noisy operations are wearing ear plugs. We have purposely attempted to sell the program rather than "force it down their throats," feeling that this approach will pay "better dividends" in the long run. We have purposely avoided the scare technique and, while the way we are doing it may be a bit more difficult, I am sure that it is better.

The advent of jet engines, especially with after burners, has posed additional hearing protection problems and this we have tried to solve by furnishing our own developed Lockfoam Earmuffs, along with our regular earplugs.

In conclusion, I hope I have not given you the impression we have the hearing problem solved, because we haven't. We still have a long way to go. We have, however, faced up to the problem and have made substantial progress. This task of getting thousands of rank and file employees educated and wearing ear plugs is not easy, but I feel it can be done and I feel that Lockheed will do it.

Practical Aspects of a Hearing Conservation Program

JAMES R. SHEEHAN, Industrial Hygienist
Long Beach Naval Shipyard
Long Beach, California

IN THE STUDY of noise and hearing as well as in other fields of scientific research there is often a large area of information

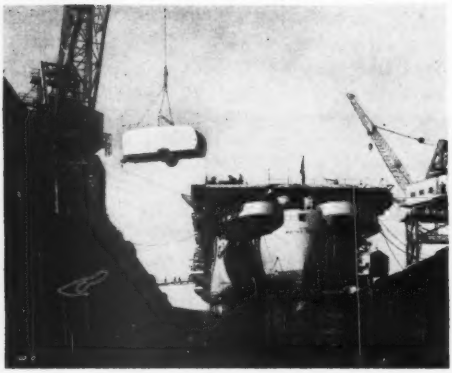


Fig. 1.
Moving "test room on wheels" to work site.

which remains undefined and inexact; between, on the one hand, the purely research phase of the work, and on the other, the purely applied phase. The problem of hearing conservation is no exception. Practical questions such as, "what is a dangerous level of noise exposure?" and "what type of ear protectors are the best?" are frequently presented to the researcher and are difficult to answer without qualification. In this short discussion, an attempt will be made to give you a partial view of how this gap may be bridged, and how the benefits of scientific research on noise and hearing can be brought out of the laboratory and back to the industrial environment where real savings in human hearing can be accomplished.

A noise research and hearing conservation program was initiated at long Beach Naval Shipyard by the Medical Department of the Shipyard and executed through the cooperation of the Subcommittee on Noise in Industry of the American Academy of Ophthalmology and Otolaryngology. Individually, the immediate interests of the Medical Department were primarily the conservation of hearing at the Shipyard itself, while the Subcommittee sought field and laboratory data in order to study specific questions regarding industrial noise exposures such as audiometric procedures, frequency analysis of industrial noises, and permanency of hearing losses, etc. These data would be of value in hearing conservation throughout industry.

An intensive field and laboratory research program was begun and continued at full operation for a period of six months during which time, approximately, 600 field audiograms were taken on employees brought directly from a noisy industrial environment to a sound insulated booth near the work location where pure tone audiograms were taken. Tape recordings of industrial noise, noise frequency analysis, and sound levels were among the other field data gathered (Fig. 1).

In field observation and in questioning of test subjects it was evident that although some of the approximately 2500 employees exposed to high noise intensity levels were conscientious in wearing ear protection, there was a large group working under the same conditions without ear protection.

Preliminary analysis of data showed significant hearing losses in older age groups. Specifically, it was found that the hearing loss of welders, boiler-makers, and foundrymen in the age group above 30 years was greater than would be expected from the average population, indicating that these employees had been exposed to noise which may have produced a hearing loss. To conserve the hearing of such employees, it was necessary to institute the wearing of ear protection on a more complete scale, and it was decided that the best way to do this was through an educational program. The educational program consisted of two parts: first a motion picture on noise and hearing prepared by the Subcommittee was shown followed by a lecture period accompanied by recorded sound demonstrations of high intensity noise gathered in field studies. At the close of the meeting which lasted 30 to 40 minutes, a short discussion on ear plugs was given and a set of wax impregnated cotton plugs given to each man with the explanation that either this type or a permanent rubber type was available. Approximately fifteen meetings were held with a total attendance of about 1500 persons. All were exposed to high intensity level noise in the course of their duties. Master mechanics and foremen of the respective shops also attended. A check of issues of ear plugs showed a marked increase in demand for plugs with some preference for the new soft rubber V51R plug. The interest shown by employees has been sustained at a high level

over the six month period since the educational program was completed as shown by the fact that 50 to 100 permanent type ear plugs are fitted in the dispensary each month.

Previously, it had been the policy to issue ear plugs, along with other protective equipment at the Safety Equipment Issue Department with the employee fitting his own ear with the size he believed most comfortable. For several reasons this practice is undesirable and a procedure was instituted of fitting all ear plugs at the dispensary by an audiometrist under the supervision of a physician.

All employees exposed to high intensity level noises are given a pre-employment audiogram along with their regular physical examination, and it is particularly important that these audiograms be reliable and performed in an approved manner since, in addition to other values, they may constitute important evidence in litigation for loss of hearing compensation. Although personal factors in taking an audiogram may eventually be eliminated, these factors still control to a large extent the accuracy of an audiogram which makes it imperative that a person skilled in audiometry prepare the audiogram. A testing room which has a constant low level of noise is, also, essential for reliable audiometry. Simply locating a quiet room is, in general, an inadequate procedure since an extraneous noise, such as a passing automobile, may invalidate at least part of the data, and in defending the accuracy of an audiogram, this is certainly a vulnerable factor. For this reason and others, a prefabricated sound insulated booth was installed in the Medical Department and training in audiometry for Medical Department personnel instituted. This has not only permitted accurate audiometry, but it has brought a favorable response from employees.

Arbitrarily, if an overall noise intensity of 90 decibels is considered sufficient to produce hearing loss in continued personal exposures, it is certain that individuals will vary considerably in the degree of hearing loss produced from this exposure with some showing no loss at all while others show readily measured losses. Another factor to be considered is that noises vary widely in frequency and it is believed that losses produced in individuals will also vary with the spectrum of the noise exposure although the overall intensity remains the same. For these reasons, in addition to pre-employment audiograms, it is necessary to perform periodic audiograms to locate ears with particular susceptibility to noise and to prevent further loss of hearing. In performing periodic audiometric examinations on individuals brought from noisy environments, it is important to note whether any exposure has occurred before reporting for the audiogram since temporary hearing losses from exposure may produce an erroneous audiogram.

Pre-employment audiograms, therefore, become valuable in establishing normal hearing since no recent exposure to high intensity level noise is probable.

Before the hearing conservation program had been initiated at Long Beach, a large group of employees had been employed without pre-employment audiograms and it was necessary to obtain these audiograms since approximately one-third of all employees are exposed to potentially damaging noise levels at least part of the working day. To call all employees to the Dispensary for audiograms would be an expensive process, and it was decided that since all employees visit the Dispensary at least once a year, an opportune time to obtain audiograms would be at the time of the visit to the Dispensary for occupational or personal illness or accident or for an annual chest x-ray. This program is currently in operation and appears to be working satisfactorily. To perform annual audiograms on all of the 2500 exposed personnel would require a rate of approximately 45 per week. Currently, approximately 64 audiograms are performed per week of which 15 are pre-employment.

Reaction of employees to the hearing conservation program has been encouraging. At the beginning of the program many patients expressed apprehensions concerning the results of the audiograms. They felt that a proven lack of hearing might result in the loss of their position or endanger their chances of promotion. The older employees stated that they did not object to it. A few ridiculed the use of ear plugs, and expressed an objection that they would be unable to hear spoken voices when using ear plugs.

Fig. 2.
An operation at which ear plugs are worn.

Some employees stated that on their own initiative they had used ear plugs in the past. They complained that the plugs were not properly fitted and caused pressure and ringing in their ears both during and following the use of ear plugs.

During the initial interview at the receptionist desk these complaints were overcome by explaining the purpose of the Hearing Conservation Program. Their fears relative to the loss of their position or promotional opportunities were allayed even though their loss of hearing was proved. Pointed out were personal advantages to the individual, such as conservation of hearing, free audiograms, free issue of ear plugs with proper fittings under the supervision of a physician.

All referrals for audiograms have been on a strict volunteer basis. As the program progressed and its intent was fully understood no complaints have been registered by patients before or after audiograms, and their cooperation has been excellent.

In the early stages of the work, great interest and cooperation was shown in the field measurements and in the field audiograms taken. In the educational demonstrations in which noise intensities as high as 120 decibels were played through a special amplifying system in a quiet lecture room, thereby simulating field conditions, considerable personal interest was taken as shown by questions asked afterward with the almost painful realization that high intensity noise is considerably more than a nuisance. In the fitting and issue of ear protection, employees have shown appreciation to personal fitting of plugs. Many expressed the thought that such a program should have been instituted at an earlier date. Some have voluntarily appeared during their lunch hour and at other times to take advantage of the service. Although each employee is told in a general way what his hearing is after having an audiogram, no claims for hearing loss have been received.

Wearing of ear protection is, of course, less than 100% in force, and some employees continue to work in high noise intensities without ear protection. As yet, no official instructions requiring the wearing of ear protection have been issued. Through continued efforts, particularly in audiometry and education of personnel exposed to high intensity noise, it is believed possible to achieve a degree of employee cooperation which will essentially eliminate industrial hearing loss (Fig. 2).

Ryan's Hearing Conservation Program

ADOLPH BOLGER
Assistant Superintendent of Fabrication
Ryan Aeronautical Company
San Diego, California

THE RYAN Aeronautical Company became concerned with the problem of ear protection for production employees a number of years ago. The Ryan Safety Department attacked the problem in the area of greatest hazard—the drop hammer forming department.

Generally, the most satisfactory solution to noise incidence, which contributes to loss of hearing and ear irritation, is accomplished by reducing the noise at the source. However, in some cases, this cannot be done, either because it is not technically possible or cannot be accomplished within a short period of time. In the Ryan drop hammer department, where impact forming is performed, noise and vibration are inevitable factors.

Ryan safety engineers decided to protect the hearing of employees in this department with ear plugs. According to tests conduced at Harvard University, in 1943, ear plugs had afforded welcome relief from the

Fig. 1.
Employee making his own selection of ear plugs.

discomfort of exposure to intense noise. In addition, when the ear plugs were properly selected for size and made of the proper type of soft rubber, they did not interfere with voice communication. In some cases, employees found it easier to hear in the atmosphere of noise, when other employees spoke to them and they were wearing properly fitted earplugs.

Previous to our program of protection, a number of Ryan employees were using make-shift ear plugs of cotton. This practice often resulted in ear infection cases and did not seem to prevent a steady loss of hearing to certain employees, over a period of time.

Our program took the form of carefully screening some of the most responsive employees and selling them on the idea of using the proper ear plugs. We believe that if they used the ear plugs with success, they would be influential in selling the idea to the other employees. In the beginning, we were under the erroneous impression that we should select one type of ear plug, which seemed to be superior, and ordered it in all sizes. We believed that by doing this we could fit the ears of all employees and standardize on our inventory requirements.

However, we soon learned that the human ear is not only of different size, but of a variety of shapes. We found that it was eminently better to allow the employee to select his type and size of ear plug from a variety of types. Psychologically, employees are much happier with the ear plugs which they select and are far more willing to wear them when they feel that they have been consulted and given an opportunity to choose those which seem to best fit their ears, both as to size and brand (Fig. 1).

In the early period, we received a number of complaints such as, "my ears hurt," and "these plugs are uncomfortable," and "I just don't like to wear ear plugs." But as the program progressed, and we began to explain to employees the advantages of wearing ear protection, these complaints dwindled away.

Incidentally, in our explanations and our "selling" of the use of ear protection, we showed the employee that these ear plugs were obtained and distributed for his protection, alone. We went to some detail to show the employee how excessive noise and vibration could affect his hearing and how the ear plugs were designed to isolate him from this hazard.

At no time in our presentation, did we discuss the matter of loss of hearing claims under Workmen's Compensation, or other financial aspects of this problem, because we felt that the basic motive of the employees to which we could appeal was that of physical protection and safety and a more desirable environment in which to work.

The ear protection program has succeeded. At this time, every employee working in our drop hammer department and in the areas adjacent is wearing properly selected ear plugs and is well disposed to their use. These devices have become an accepted piece of equipment in these noise-prevalent occupations. In addition to the mental and physical health which the ear protection program has engendered, it has produced a number of welcome employee relations improvements. Employees with sensitive ears have not had to transfer to other work or to leave the company's employment because of the noise irritation. Employees in the drop hammer areas were able to work with increased efficiency and were, therefore, better satisfied with their work environment. A higher morale automatically developed in the employees in these areas which was evidenced in better labor-management relations.

During the indoctrination period, when the ear protection program was being in-

augurated, the Ryan safety department worked very closely with management and looked to the management group for guidance and advice. Through this close liaison, the program was gradually inaugurated with satisfactory results.

It is interesting to note that Ryan employed a number of deaf and deaf-mute employees in these noisy areas during World War II, and still employs these partially handicapped people. They have worked very well in these critical areas because instead of being "handicapped" they are actually better equipped for some of these difficult tasks than normal persons. Deaf mutes can communicate through sign language even better than normal persons equipped with ear protection.

As a result of our experiences in this field, we would unhesitatingly recommend this program of education and hearing protection to any other company faced with similar hazards to health and morale.

One Approach to Hearing Conservation

RICHARD WILKINS, Chief Safety Engineer
North American Aviation, Inc.
Los Angeles

EARLY in 1941, we, at North American, embarked on a program of hearing conservation—admittedly, at that point, we did not identify it as such—in fact, we didn't quite know what to call it!

At that time, 1941, we began doing a preemployment audiogram on all prospective employees as a routine part of their preplacement physical examination. Our thought in doing this was quite basic: we wanted a record of the status of each employee's hearing. We felt that this was necessary but we weren't too sure why we wanted the information or how we were going to use it.

In the State of California, the Workmen's Compensation Act is written in such a way that aggravation of an existing condition or idiopathic weakness is compensable—so we felt that a person with good hearing or a minor loss presented a potential liability unless we had a control, or starting point, as to the status of a person's hearing when he became an employee. From that, we could at any time evaluate any differences that appeared on future audiograms.

About that time we checked the market and chose what we believed to be the most effective type of ear protective equipment—it turned out to be the rubber stopple type. We purchased adequate supplies of these and made them available to all employees who desired to use them.

Since the inception of our pre-employment audio system, we have flagged those persons whose hearing falls below what we consider normal hearing. When we found such a person, we completed what we called "Physical Examination Conditional Agreement."

This form states that the employee has "Impaired Hearing" and states, "Company-furnished ear protection must be worn in high noise level areas or operations, i.e., power hammer, engine run-up, riveting, jack hammer, etc." The employee, company doctor, and safety engineer all sign the form and copies are routed to the employee's department, personnel records, medical file, and safety file. All employees working in high noise level areas and placed on this type restriction are periodically given audiograms (every six months) and are checked on the job by a safety engineer to see if they are complying with the work restrictions or conditions of their employment.

Recently, with the advent of titanium and other hard materials, the noise levels have increased and therefore it has been necessary to take a different and more direct approach to the hearing problem—we are in that phase now.

It was our desire at this point to bring our employees into closer contact with the noise and hearing problem. This was done in three phases: (1) Several informational type bulletins were prepared for employees telling them the steps that were being taken by the company to combat noise at its source and the fact that ear protective equipment was the best practical approach. (2) A research type program was conducted in conjunction with the Subcommittee on Noise in Industry—120 to 130 employees were used to measure the effectiveness of ear- or hearing-protective equipment. (3) A booklet, "Hearing Conservation," has been prepared which will be issued to employees explain-

ing the facts of the problem and their part in the solution. The booklet explains that noise can cause hearing loss, but this loss can be prevented with appropriate precautionary measures.

After the booklet has been issued and all employees have had an opportunity to procure ear protective equipment—(we now offer a choice of various types) we, no doubt, will follow with a mandatory type of program in all sections which we find are high noise level areas.

It is our feeling that this type of employee-relations selling will do much to insure the success of a hearing conservation program and when we are ready to establish a mandatory rule, we are certain that it will be accepted.

We believe all employees will go along with us on this program—we feel that they are intelligent adults and if they are told the honest facts of the problem, they will accept the necessary precautions to protect themselves.

(EDITOR'S NOTE—The booklet "Hearing Conservation" mentioned in MR. WILKINS' paper was prepared by North American Aviation, Inc., and the Research Center of the Subcommittee on Noise in Industry. Copies may be obtained by writing RICHARD WILKINS, Chief Safety Engineer, 5601 Imperial Highway, Inglewood, California.)

What We Know and Don't Know About Noise Control*

CHARLES R. WILLIAMS, PH.D.
Director, Industrial Hygiene Services
Liberty Mutual Insurance Company
Boston

AS THE INTEREST in noise control spreads, more and more engineers face the problem of how to go about quieting specific noise sources. The quest for a quick, simple and inexpensive solution is universal. There are many such answers to individual problems, but unfortunately there is no simple general panacea. There are many noises which we do not know how to handle, but even these will ultimately be solved.

*This is a summary of the original presentation by DR. WILLIAMS, who was unable to supply the complete address because of the pressure of other commitments.

The first important step is to appreciate that there is a problem. The next is to understand fundamental noise control principles and apply them with ingenuity.

Two questions are frequently asked. The first is—"Isn't there some kind of ray or counter noise which can be used to cancel out the noise?" This is an expression of the hope for a simple cure-all. There is research being done in this direction and some success has been achieved for pure tones over relatively small areas. It is, of course, possible that there may be some specific applications of this principle to industrial noise. At the present time, however, this is a rather dim hope. We should not stop all attempts at noise control and wait for such a pat answer.

The second question refers to the possibility of sucking-up noise. The closest approach to an answer to this question is the use of sound absorbent material as a final answer.

General application of acoustical material has a definite place in the noise control field, but there are limits to its application. The main function of such materials is to reduce reverberation. They provide noise reduction in areas away from the noise source—they do little for people in the direct sound field.

At the present time, it can be stated that we do not know how to control industrial noise by cancellation of noise—and we cannot solve all our problems with acoustical materials. Our major approach to controlling hazardous noises is still to control noise sources. Following are some examples of what can be done:

1. *Acoustical Enclosure*—What can be accomplished by various types of acoustical enclosures and the important principles involved have been demonstrated. (Industrial applications of enclosure were illustrated by tape recordings.)

2. *Substitution* or *Change in Operation*—Factors such as cost, effect on production and quality of work must be satisfied before an operational change is acceptable.

3. *Compressed Air Nozzles* are frequently noise problems whether used for blow-off or ejection of parts from presses. It is possible to design a nozzle which will maintain the necessary thrust to do the job and still be substantially quieter. (Illustrated by tape.)

4. *Air Tools* are sources of high frequency, high intensity noise. A silencer designed for an air-driven screwdriver provides reduction to levels below present tentative damage risk criteria. (Illustrated by tape.) This silencer consists of a series of copper tubes whose length is related to the wave length of important frequency components of the noise.

5. *Air Hammer*—The noise from an air hammer, used in paper box industry, consists of two major sources—the air and the chisel. The air noise has been quieted by means of a muffler and a piece of rubber tubing; the chisel noise is still under study and promising results have been obtained by substituting nylon for steel in the chisel.

6. *Circular Saw Blade*—There are three kinds of noise from wood sawing operations —resonance of the blade; a siren effect from the chopping of air by the teeth; and the impact of the teeth against the wood. In production shops where a saw is used for long periods of time with the same blade setting, it is possible to reduce the high frequency resonance by means of a metal stiffener mounted next to the saw blade. The diameter of the stiffener should be as large as possible, consistent with the depth of cut. (Illustrated by tape.)

7. *Reducing Single Impact Noise*—The noise of metal parts banging down metal chutes or into tote boxes is one of the most common in the metal processing industry. All attempts to meet this problem by such means as applying automobile undercoating have met with failure. Considerable reduction can be obtained, however, by constructing a sandwich consisting of the original steel part, cardboard or roofing paper and a sheet of thin metal. This results in substantial reduction of the high frequency components. The technique has been applied to both tote boxes and metal chutes with considerable success.

These few examples are given to illustrate the things which can be done to reduce noise at its source. The possibilities are unlimited. One must first evaluate the problem and then apply well-known acoustic principles as well as a considerable amount of ingenuity. These ingredients can solve many noise problems. Others are not so simple. For these considerable research will be necessary.

The Present State of Development of Muff-Type Ear Protectors

WILLIAM B. WADSWORTH, Consultant
David Clark Company, Inc.
Worcester, Massachusetts

SINCE considerable strides have been made quite recently in ear-cup or muff-type ear protectors, it seems appropriate to describe their design briefly, and outline the ear protection they provide as compared to ear plugs.

Effective ear plugs were developed over a decade ago, and up to recent times have afforded more ear protection than the muff types. Hence it is natural that most people would feel that plugs are the only really effective ear protection, even though their concomitant problem of acceptability by the people requiring them has been most difficult of solution. This same problem that industry has had regarding acceptability of ear plugs was found to exist to an even greater extent in the Armed Forces where ear protection was imperative. We became interested in improving the muff type ear protector since it appeared to have ample acceptability, although it did not afford adequate protection against the highest noise levels such as jet engines. This work was started by us in early 1953, and within the last year we have designed a muff-type ear protector to be used in noise fields as high as 155 decibels. At the same time this muff-type protector affords reasonable wearing comfort to the user.

Before describing the design and characteristics of this new type of muff ear protector, a brief general description of muff-type protectors will be given. A muff-type protector looks very much like a pair of ear phones. However, the phones are replaced by reasonably rigid cups, large enough to enclose the external ear. In order to effect an airtight seal without discomfort to the user, a ring of soft sealing material is placed between the cup rim and the surface of the head around the external ear. With vinyl plastics available today, a good seal with reasonable comfort can be obtained with no

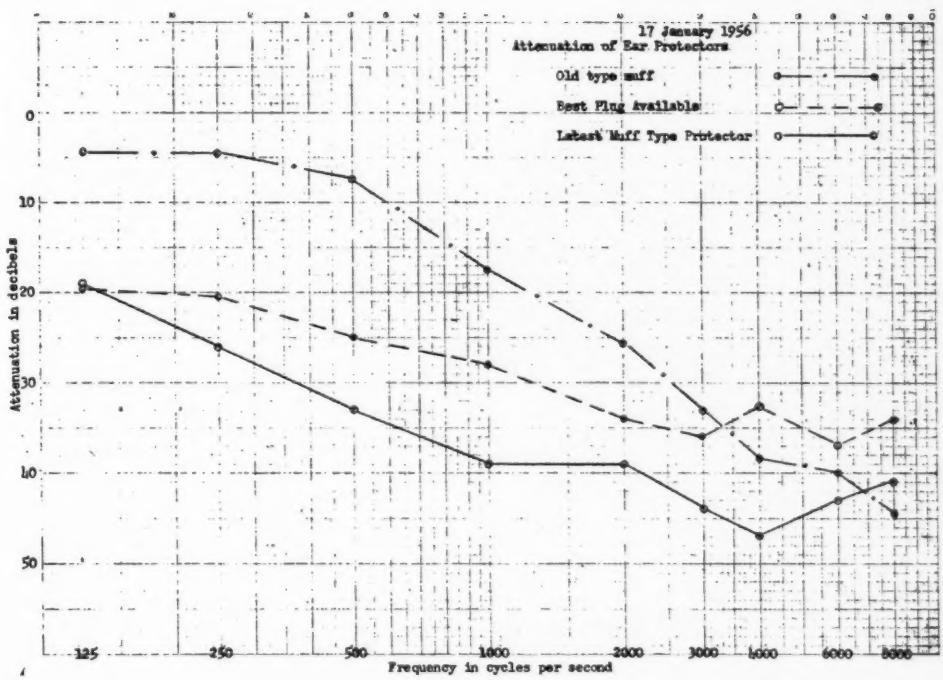


Fig. 1.
New muff type protector.

deleterious effects on the skin itself. The headband also exerts several pounds force on the cups to further ensure a good seal.

It was found by us in measuring the attenuation of prior muffs, that little attenuation was afforded at the lower frequencies (under about 1000) and only moderate attenuation at higher frequencies. The lack of low frequency attenuation was attributed to a "resonance" phenomenon by prior workers. An increase in the weight of the muffs was thought by most people to be the only way to increase low frequency attenuation, which, however, was impractical from the wearer's point of view. It appeared to us that since all prior muffs afforded inadequate protection, a quite radical change in design was required. The new design finally accepted used a larger muff volume, while at the same time having the minimum area needed to enter the external ear into the ear cup itself. This design not only increased the low frequency attenuation a great deal, but improved it at all frequencies. Overall uniform noise (white noise from 100 cycles to 10,000) is reduced by order of thirty-five decibels. A curve showing results of our measurements comparing this new muff design to a prior muff and the most used ear plug indicates that this new muff type protector is considerably better than even the best ear plugs (Fig. 1). The new muff is shown in Fig. 2. Its total weight is about three quarters of a pound. Headbands of different tension are available and some have adjustable tension built into the headband. They have been worn for many hours at a time, with quite reasonable comfort. Some have suggested that plugs and muffs be used in combinations. With the newly designed muffs, this is unnecessary and may even give less attenuation at some frequencies than the muff alone. This somewhat surprising result is probably due partly to reducing the terminating volume for the ear canal which in-

Fig. 2.
Attenuation of ear protectors.

creases bone conduction, and partly through preventing fortuitous sound cancellation when an ear plug is worn in combination with a muff protector. The very fact that bone conduction (i.e., sound path to the ear through the bony structure of the head) increases when an ear plug is used, means that the maximum attenuation possible with ear plugs is considerably less than with ear muffs. This effect increases as frequency is decreased and is about 10 decibels at 1000 cycles and about 20 decibels at 100 . With muffs available now that approach the presently accepted limit in attenuation at many important frequencies (i.e., approach the bone conduction or leakage limit), this factor becomes important.

In many applications where ear protection is used in high level sound fields, the problem of communication becomes very complex. Since usually phones are used over the ears and must be protected from the high ambient noise levels, it would seem obvious that muff-type protectors are preferable to ear plugs. It has been reported to us that satisfactory communication is possible using phones in our ear muffs in levels as high as 155 decibels (created by after-burner jet engines).

It always takes time to educate people to new forms of personal protection, and ear protection is no exception. Unfortunately, damage to hearing is a slow insidious process and with poorer hearing the subject feels less need for protection. Even though there doubtless will always be some degree of discomfort, regardless of the type of protectors used, we have had to use very little persuasion when people are subjected to high noise levels, however.

The question of the relative cost of the various types of ear-protectors is difficult to answer at this time. Obviously muff-type protectors are much more expensive than ear plugs on a per unit basis. However, it has been found in the Armed Forces that the high rate of loss of plugs would, over a reasonably long period of time, equalize or possibly exceed the cost of the muff type protectors. It is believed by us that no one type of ear protector is the answer to all noise problems, but that each noise problem should be given careful consideration as regards the type of protector used. The important purpose of this paper is to point out that contrary to many past opinions, muff-type ear protectors are now available on the market that actually afford more protection against the deleterious effects of noise than insert type devices. Therefore, the most extreme noise problems at present can best be solved by using muff type protectors. In noise problems where either type of protection is adequate, as pointed out previously, the choice should be decided by proper evaluation of other circumstances.

Summary of Proceedings

HERBERT T. WALWORTH
Director of Industrial Hygiene
Lumbermens Mutual Casualty Company
Chicago

IT SHOULD be an easy task to summarize the Conference because the papers presented cover certain specific subjects concisely and thoroughly. However, this is not the case because of the difficulty in selecting the really important phases of so comprehensive a program and recount them in a paper of reasonable length.

This Noise Conference could have been called "A Program for Hearing Conserva-

tion in Industry" for it covered the various phases of the noise problem now confronting industry. The papers presented can be classified into five groups dealing with various aspects of industrial noise: (1) Principles of hearing measurement. (2) Principles of ear protection. (3) Practical problems in industrial ear protection. (4) Principles of noise control. (5) Practical applications of noise control.

A hearing conservation program for industry encompasses several separate and distinct activities requiring a number of professional skills. The physician, industrial hygienist, nurse, acoustical engineer, audiologist, plant engineer and worker all contribute to the goal of hearing conservation.

An essential step in hearing conservation is the measurement of hearing acuity. Presently, this is done with pure tone audiometric equipment. Research work is in progress on the development of speech audiometric procedures which may eventually be of interest industrially.

It is difficult to outline an audiometric program which will fit all types and sizes of industry in all states. However, there are certain principles which apply to all situations and these should serve as guides. Perhaps the two most important considerations in an audiometric program are the selection of an adequate room for testing and calibration of equipment. High background noise and malfunctioning audiometric equipment can easily render the testing results worthless. Other matters for consideration include selection and training of personnel for audiometric testing, recording noise exposure history, and establishing who will receive examinations and under what conditions.

Much has been said and written about the value of ear protection in hearing conservation. However, this conference was the first to clearly define the basic principles and to establish the important considerations of ear protection programs.

It was pointed out that the most important hearing frequencies range from 300 to 3000 cycles per second. Since hearing loss occurs one-half to one octave above the frequency of the damaging noise exposure, some idea is gained of the requirements of ear protectors for adequate protection. The best ear protectors are usually composed of pliable or semi-pliable plastic which insert into the ear canal. Most of the acceptable protectors on the market will provide 10 to 15 decibels attenuation below 1000 cycles per second and 15 to 40 decibels above 1000 cycles per second in regular field use. With adequate knowledge of the noise exposure, it should be possible to estimate the degree of protection to be expected. It was reported that ear protectors do not interfere with the understanding of speech and the usual industrial signals.

There are differences of opinion relative to the practicability and value of earmuffs for protection against noise. Perhaps further research and development will help to clarify this problem. However, the proof of their value will rest with industry. If they are acceptable to the workers and provide the necessary protection, their value to industry will be established.

The distance between the theoretical and practical usually is great. This conference emphasized the practical problems of ear protection and helped to bring both the theoretical and practical problems into focus. The reviews of specific ear protector programs should help point the way for more extensive application of ear protection, especially in those industries where the control of noise by engineering methods is impractical.

Whatever the approach to an ear protection program, it seems certain that considerable thought must be given to program organization and then the exercise of close employee supervision to insure desired results.

The control of any hazard at the source or by other engineering means, usually is preferable to the provision of personal protection. In approaching the problem of noise control an understanding of the basic principles involved is essential. These principles are: (1) substituting less noisy operations; (2) eliminating noise at source; (3) isolation of noise source or worker; (4) increasing distance between noise source and exposed workers; (5) providing sound absorption; and (6) personal protective equipment.

The many specific examples of noise control discussed involve one or more of the basic principles of control just outlined. A

few of these are summarized briefly:

Control Method	Basic Control Principles Involved
Flame gouging (welding)	Substitution (for chipping)
Bracing equipment	Control at source
Enclosing equipment and use of acoustical materials	Isolation and absorption
Covering gears	Enclosure or isolation and absorption
Rubber wheels on movable equipment	Control at source
Enclose noisy operation	Isolation
Dampening vibrating castings	Control at source
Hopper reinforcement	Control at source

When approaching the problem of control, it is important to remember that it is not necessary to eliminate the noise entirely. Frequently it will be necessary to reduce the noise exposure only by five or six decibels in one or more octave bands. Thus, the first step involves a thorough study of the exposure so that the benefits derived by any given control procedure can be followed closely.

Industry should not overlook the possibility of specifying standards of noise control in the purchase of new equipment. If manufacturers are to be held responsible for loss of hearing among their employees, the designers and producers of manufacturing equipment should accept a share of the responsibility for noise control.

There are no set procedures for establishing a hearing conservation program in industry. However, the potential importance of this problem suggests the need for a positive program wherever potential noise hazards exist. A possible approach might be as follows: (1) Make one person responsible for program (either part or full time). (2) Outline a hearing conservation program. (3) Evaluate noise exposures. (4) Establish noise control areas. (5) Establish a noise control committee. (6) Establish an audiometric testing program.

Assistance in establishing the program is available thru a number of sources. Some of these sources include industry organizations, scientific organizations, official agencies, insurance carriers and private consultants.

The tools for meeting the loss of hearing problem are rapidly being made available to industry. This conference has contributed materially to our present knowledge, and much progress can be made by putting these tools to good use.

(EDITOR'S NOTE—The Conference also included a presentation entitled "Principles of Sound Absorption and Isolation" by KENNETH C. STEWART, Research Associate and Lecturer, Graduate School of Public Health, University of Pittsburgh. Unfortunately this material is not available for inclusion in this publication.)

Four Air Pollution Studies

THE PUBLIC HEALTH SERVICE has made contracts with three federal agencies for research studies in the field of air pollution. . . . The National Bureau of Standards will study analytical methods for determining common pollutants and will strive to develop means of identifying various combinations of pollutants. . . . The Bureau of Mines will study waste incineration as a contributor to air pollution and will evaluate stack effluents and the exhaust of internal combustion engines. . . . The Weather Bureau will study dilution of atmospheric contaminants, and will investigate methods of predicting weather conditions that might aggravate air pollution.

Iodometric Monitoring
OF BORON-CONTAINING ATMOSPHERES

WILLIAM H. HILL, Ph.D., GEORGE J. LEVINSKAS, Ph.D., WILLIAM J. NOVICK, Jr., B.S.
Department of Occupational Health, Graduate School of Public Health
University of Pittsburgh, Pittsburgh, Pennsylvania

THE DETECTION of gas contaminants, whether in industrial gases, plant atmospheres, or the air of experimental animal gassing chambers, has always posed numerous problems. Their quantitative determination is facilitated when concentrations are high, for it will usually suffice to obtain grab samples with the aid of a gas pipette.

However, for low concentrations of the contaminants, either unreasonably large gas sampling containers or dynamic sampling methods and devices must be employed. Similar expedients are also necessary if the available analytical procedure is not very sensitive. Confined areas around experimental or industrial laboratories often make dynamic methods very awkward to use.

Another complication arises immediately if the contaminant or its solution is not stable for a sufficient length of time, e.g., if destruction by hydrolysis must be reckoned with. This could gravely affect the results obtained by either static or dynamic sampling procedures.

The manufactured gas industry has recognized these factors for a long time and it has used a tool for effective in-plant gas analysis, especially for the contaminants hydrogen sulfide and hydrogen cyanide, which should find ready application in industrial hygiene practice. It is known as a Tutwiler Burette[1] and is, in effect, a combination of a gas pipette and a burette which permits direct titration of the gas contaminant in the sample. By properly adjusting the titer of the standard solution used for a particular reaction, the burette reading (in ml or 0.1 ml) can be made to express the concentration of the gas contaminant in any desired way, such as ppm, grains per 100 cu ft, or mg per cubic meter. This obviates separate calculations for each analysis. Fig. 1 illustrates this very useful gadget. It can be bought in a handy carrying case which also has provision for the standard solution needed for the titration, so that the equipment is mobile and can be transported anywhere in a laboratory or plant where an analysis is to be carried out. A Tutwiler Burette is operated in the following manner.

Fig. 1. Tutwiler Burette

It is filled completely with a barrier liquid (e.g., starch water) by means of a levelling bulb connected with its bottom stopcock through rubber tubing. The top stopcock is connected to the gas or air stream to be analyzed, and a gas sample (100 or 500 ml, according to the size of the burette) is drawn by properly manipulating both stopcocks and the levelling bulb. Actually, an excess of gas volume is drawn into the burette, then the top stopcock is closed, the levelling bulb is raised to compress the gas volume to the 100 or 500 ml mark, the bottom stopcock is closed and the one on top opened momentarily to allow the collected gas volume to attain pressure equilibrium with the surrounding atmosphere. In this way, the gas sample is always obtained under prevailing barometric and temperature conditions and proper volume allowances to standard conditions can be made if so

desired. The bottom stopcock is then opened again, the levelling bulb lowered so as to put the gas sample under a slight vacuum and the stopcock is closed again. The levelling bulb is disconnected, the small burette on the top is filled with the standard solution used for titration of the contaminant, and titration is carried out right in the gas pipette portion of the Tutwiler, with vigorous shaking in order to contact the gas with the barrier liquid and titrant.

This tool was very much in our minds during past years of developmental work on methods for the direct analysis of boranes with which we have been concerned in our toxicological investigations. Unfortunately, there was no analytical procedure available that would have permitted the use of the Tutwiler, a spectrophotometer being required in each known method of analysis.

It may be recalled that boranes, or boron hydrides, are compounds of boron and hydrogen, similar in many respects to the compounds of carbon and hydrogen, which, according to Hurd,[2] have gained considerable industrial importance for the surface hardening of steel, the bonding of ceramics to iron and graphite, the vulcanization of rubber in lieu of sulfur, and as initiators in vinyl polymerization. Some of the boranes, such as diborane (B_2H_6), are gases under normal temperature and pressure conditions, others are liquids (e.g. pentaborane, B_5H_9), and still others are solids (e.g. decaborane, $B_{10}H_{14}$) which may or may not have relatively high vapor pressures at normal room temperature. The boranes are quite soluble in many organic solvents and will react therewith if they contain active groups. They are fairly stable in solutions in hydrocarbons. They dissolve very little in water and hydrolyze therewith to boric acid and hydrogen, the speed depending on the borane involved. The boranes enter rather stable unions with inorganic and organic nitrogen compounds often yielding salt-like compounds which dissolve readily in water and suffer little from hydrolysis. Dimethylamine-borane ($(CH_3)_2$ NH BH_3), one of these latter compounds, will be dealt with in this paper.

In our continuing efforts to develop analytical methods for the boranes, use was made of the observation of the senior author that decaborane reacts with iodine solution quite readily. Feinsilver[3] has shown that diborane reacts with bromine in a glacial acetic acid solution with the formation of boron tribromide, the excess bromine being determined by U. V. spectroscopy. On the basis of these known facts, it was postulated that it should be possible to titrate boranes directly with standard iodine solutions, with hydrogen iodide and boric acid as the end-products. This would permit the use of a Tutwiler Burette for static gas analysis and eliminate the need for expensive spectrophotometers. The great atomic weight of iodine and the large amounts required for destruction of the boranes should make for excellent sensitivity. The following equations bear this out.

$$B_2H_6 + 6\ I_2 = 2\ BI_3 + 6\ HI$$

diborane
27.7 1523

$$B_5H_9 + 12\ I_2 = 5\ BI_3 + 9\ HI$$

pentaborane
63.2 3046

$$B_{10}H_{14} + 22\ I_2 = 10\ BI_3 + 14\ HI$$

decaborane
122.3 5584

Thus the boranes mentioned here require 45 to 55 times their own weight of iodine. In other words, 1/10 ml of a 0.01 N iodine solution should detect 2.8 micrograms of decaborane which, in a Tutwiler Burette of 500 ml capacity, would be a little over 1 ppm. The use of a more dilute, e.g., 0.001 N, iodine solution and its addition from a microburette should permit even greater sensitivity. The starch-iodine color reaction is so very sensitive that it can be used to determine the endpoint even at the suggested dilutions. Clearly then, such a method would be operative at borane levels at which monitoring of animal chambers, plant atmospheres, etc., by the Tutwiler method would be desirable.

Preliminary laboratory tests with dimethylamine-borane showed that the principle of the proposed new method is, indeed, sound. This borane was found to react with iodine solution speedily, completely, and according to theory, as shown in the example of the following macrotitration.

A solution of dimethylamine-borane was prepared by dissolving 0.1178 grams (0.002 mole) of the material in 500 ml of water (volumetric flask). Aliquots of 10 ml of this

TABLE I.
TITRATION OF DIMETHYLAMINE—BORANE WITH IODINE SOLUTION

$$(CH_3)_2NH{\cdot}BH_3 + 3\ I_2 = BI_3 + 6\ HI + (CH_3)_2NH$$

ml of 0.01 N iodine solution used	grams dimethylamine-borane in total solution, found	% recovery
23.70		
23.65		
23.69	0.1164	98.8
23.78		
23.75		

TABLE II.
INDIRECT IODOMETRIC DETERMINATION OF DIMETHYLAMINE-BORANE
Excess of 0.01 N I_2 solution added; back-titrated with 0.0057 N $Na_2S_2O_3$ solution

mg. dimethylamine-borane	
added	recovered
5.92	5.89
1.78	1.77

solution were titrated with 0.01 N iodine solution to a starch-blue endpoint. Table I gives the results obtained. It is readily seen that both accuracy and recovery are excellent.

Similar results were obtained when solutions of dimethylamine-borane were mixed with an excess of iodine solution, allowed to react, and were then back-titrated with sodium thiosulfate solution. Table II shows the results obtained.

Application of the new method to air analysis, using the Tutwiler Burette, was carried out on chamber air (inlet) of a subacute animal exposure test with dimethylamine-borane then underway. The results obtained were compared with those derived from another method of analysis (phosphomolybdic acid-dynamic sampling)[4] and with "theoretical" values calculated from the amount of material vaporized. Agreement was very good, especially in view of the fact that the calculated values are, of necessity, averages for a whole day's run, and that the actual values at any one time may vary considerably from the daily average. It should also be pointed out that analysis by the two methods were not run concurrently but rather at intervals of about 20-30 minutes, so that closer checks cannot be expected. Table III gives the analytical data obtained in this investigation.

The actual procedure for air analysis followed substantially that given for the Tutwiler Burette in the beginning of this paper, 0.002 N iodine solution being mostly used in the small burette on top of the Tutwiler, and starch solution (iodine indicator) as the barrier liquid. In the beginning of the work we were concerned about the effect of relatively large quantities of hydrogen iodide which would be formed as a result of the hydrolysis of boron triiodide. Conceivably, this could prevent the reaction from going to completion. Therefore, we added sodium bicarbonate to the barrier liquid in the levelling bulb of the Tutwiler (1 gram per 1000 ml) in order to neutralize the hydroiodic acid formed in the reaction. We soon found this to be an unnecessary precaution, and the practice was abandoned accordingly. Perhaps the dimethylamine, which is liberated when the borane portion

TABLE III.
AVERAGE DAILY CHAMBER CONCENTRATIONS OF DIMETHYLAMINE-BORANE (IN PPM)
(Inlet Air)

Date	Iodometric[a]	Phosphomolybdic Acid (dynamic)	Theoretical[b]
9-13-54	53.2	52.5	60.0
9-14-54	51.8	49.1	64.0
9-15-54	63.2	66.9	64.2
9-20-54[c]	—	—	77.0
9-21-54	50.5	62.8	68.4
9-22-54	56.9	50.0	64.8
9-23-54	53.0	51.7	60.2
9-24-54	45.4	50.7	53.8
9-27-54	57.1	68.0	73.6
9-28-54	55.6	55.1	66.3
9-29-54	53.4	31.4	58.0
9-30-54	43.1	44.9	50.9
10-1-54	47.9	38.8	52.4
10-4-54	63.6	74.0	91.1
10-5-54	47.1	67.5	80.3
10-6-54	67.1[d]	61.4	69.8
10-7-54	59.6[d]	61.9	58.5
10-8-54	51.6[d]	56.1	54.3
10-11-54	54.2	54.8	62.4
10-12-54	54.8	53.3	61.6
10-13-54	44.5	41.2	52.7
10-14-54	71.6	92.3	100.0
10-15-54	59.5	68.0	73.2
10-18-54	—	85.5	73.0
10-19-54	63.5	60.2	61.7
10-20-54	62.8	73.6	64.5
10-21-54	56.9	59.5	69.7
10-22-54	56.4	66.5	68.7
10-25-54	44.7	44.0	44.7
10-26-54	52.6	52.3	48.8
10-27-54	48.3	41.5	46.8
10-29-54	43.1	43.2	44.7
AVERAGE	54.5	57.5	63.9

[a] Performed with Tutwiler Burette unless otherwise indicated.
[b] Calculated from generator weight loss.
[c] Exposure of animals started.
[d] Dynamic test; direct titration of scrubber contents with I_2.

of the molecule is destroyed, suffices as a buffer and thus obviates the need for bicarbonate.

It is believed that dimethylamine itself does not react measurably with iodine at the concentrations involved in our work because, if it did, the recoveries of close to 100% shown in Table I would have been unthinkable. However, there are indications of a reaction at higher concentrations and more detailed work should, therefore, be done on this problem as time permits.

Fresh stock starch solutions were prepared every 10-14 days by adding five grams of potato starch (Fisher catalog #S-514) and 25 milligrams of mercuric iodide to 500 ml of distilled water. Dilutions of this stock (30 ml per liter of distilled water) were made at least every few days for the barrier liquid in the Tutwiler Burette. While no exhaustive study was made of this point, indications are that older solutions yield higher results. It was also found that the endpoints obtained when using "soluble starch" (Fisher catalog #S-516) were less sharp.

Another factor which was found to influence the results was the cleanliness of the Tutwiler Burette itself. The starch used in the barrier liquid gradually builds up a colloidal deposit on the walls of the glass which causes lower results. This may be one of the reasons for the poor recoveries obtained with the Tutwiler on occasion, such as occurred on 10-5-54 (Table III). Complete immersion of the Tutwiler in chromesulfuric acid solution and subsequent water washing eliminates such deposits very readily.

From the work done so far there is little doubt that the iodometric method of determining boranes will be found generally applicable to all boranes, though variations in experimental conditions will undoubtedly become desirable for some representatives of this group of compounds. For instance, in the case of decaborane, some practical difficulties were experienced which seem to stem from the fact that the solvents and reagents used to put it into aqueous solution can react with iodine and, depending on their amount and dilution, give variable blanks.

Conclusions

A NEW METHOD has been described for the analysis of boranes by ordinary iodometric procedures. The large ratio of iodine reacting with a borane makes possible the use of a Tutwiler Burette for monitoring animal exposure chambers and plant atmospheres in those cases where the borane is not too easily hydrolyzed by water. Further results obtained by the application of this method to other boranes will be published as they become available.

References

1. The Gas Chemist's Hand Book. The American Gas Association, January, 1929, New York, New York, p. 463.
2. HURD, DALLAS T.: An Introduction to the Chemistry of the Hydrides, John Wiley and Sons, Inc., 1952, New York, New York, pp. 92-94.
3. FEINSILVER, LEO: Quantitative Determination of Diborane in Air. Chemical Corps Medical Laboratories Research Report No. 170, February, 1953.
4. HILL, WILLIAM H., and HILL, DAVID L., to be published.

Revised Manual

A REVISED edition of "Methods for Determining Lead in Air and in Biological Materials," has been prepared by the Committee on Chemical Procedures of the Occupational Health Section of the American Public Health Association. This manual revises a 1944 report. It includes descriptions of dithizone, spectrographic and polarographic procedures and a discussion of chemical methods, physical methods and choice of analytical methods for the determination of lead. The new edition sells for $1.25.

Free Silica in Industrial Dusts

—PHYSICAL METHODS FOR DETERMINATION

J. K. BRASCH, M.S.
School of Public Health and Institute of Industrial Health
University of Michigan, Ann Arbor

FREE SILICA has long been known as the etiologic agent in silicosis, but the problem of silicosis in the United States has not been completely solved.[1] Analyses of industrial dusts for free silica are still necessary in the evaluation of their potential harmfulness to exposed workers.

Free silica occurs in nature as a variety of minerals. These include the crystalline forms of quartz, cristobalite, and tridymite, the microcrystalline form of chalcedony, and the essentially amorphous forms of opal and raw diatomaceous earth. Many natural materials consist primarily of free silica; an example is tripoli, which is of microcrystalline structure and similar to chalcedony.

Quartz, the most abundant form of free silica, is a common constituent of industrial dusts, and has been responsible for most silicosis. Methods of analysis for free silica are devoted largely to the determination of quartz.

Because ordinary chemical analyses result in both free silica and combined silica (silica in the form of silicates) being reported merely as "silica," special methods of analysis for free silica applicable to industrial dusts have had to be developed. Chemical methods have been concerned mainly with quartz, and these are attempts to dissolve or decompose all material present except quartz by acid treatment. The quartz may then be isolated and weighed or it may be volatilized with hydrofluoric acid and determined by difference. But the main objection to these methods is that some of the quartz also dissolves, such solubility increasing with decreasing particle size, and this may lead to an erroneously low result. Also, there are certain silicates which are highly resistant to attack by the acids used.

Thus physical methods, which in general are better adapted to the determination of *minerals* than are chemical methods, have to be relied upon in the determination of free silica in most industrial dusts. *Petrographic analysis*, which in its application to industrial dusts is largely optical mineralogy, and analysis by *x-ray diffraction* are the two means which have been most widely applied. Petrographic analysis is often combined with chemical methods. Analysis by x-ray diffraction is becoming increasingly prominent. Durkan[2] has notably combined chemical, petrographic, and x-ray diffraction procedures, which he has applied to many types of atmospheric and settled dusts, but emphasizes chemical tests. Other physical methods employ *fusion, thermal change in crystal structure* (differential thermal analysis), and *sedimentation* as bases for separation.

Petrographic Analysis

PETROGRAPHIC analysis as applied to industrial dusts involves the identification and quantification of their mineral components chiefly by determination of their optical properties. But such physical properties as crystal form and cleavage, which together may govern particle shape, are also commonly noted. No single property is sufficient to identify a mineral conclusively; a combination must be used. However, a single property may be sufficient to distinguish a mineral from another with which it is associated. Some minerals can be identified by determining three or four optical properties, while others require that more be determined for identification to be conclusive.

A general method of petrographic analysis requires a polarizing microscope, or petrographic microscope as it is commonly called. Essentially, this has three features not found on the ordinary microscope: (1)

a "polarizer" below the condenser to produce plane-polarized light, (2) an "analyzer," also with plane-polarizing capacity, in the microscope tube which has its plane of polarization at right angles to that of the polarizer, and (3) a rotatable stage. The polarizer is normally in the optical system, while the analyzer may be switched in and out. Special prisms known as Nicol prisms may serve as the polarizer and analyzer, or various polarizing materials (such as Polaroid) may be used. When the polarizer and analyzer are both in the optical system (their planes of polarization being at right angles), the field is dark and the condition—important in petrographic work—is referred to as "crossed Nicols." Objectives and eyepieces to obtain magnifications over a wide range, as well as various accessories, may be used.

The optical properties of greatest significance (all of which are not independent) are:

(1) *Index of refraction* is a measure of the power of a substance to refract light. Amorphous minerals have one index; crystalline minerals have one, two, or three indices depending on their internal structure.

(2) *Birefringence* is a measure of the amount of separation of light rays which occurs in a crystalline mineral having two or three refractive indices. Birefringence is commonly expressed as the difference between the maximal and minimal indices of refraction. Closely related to birefringence is *interference color*, or the color a particle appears under crossed Nicols. This color depends on birefringence, particle size, and orientation of the particle on the microscope stage.

(3) *Pleochroism* refers to the change in color that the particles of some crystalline minerals exhibit on being rotated 90° in polarized light (polarizer in, analyzer out of, the optical system).

(4) *Extinction angle* refers to a crystalline mineral the particles of which have characteristic elongation, and thus an easily determinable crystallographic axis. If this axis coincides with an optical axis and a particle is aligned with the plane of the polarizer, the particle will be at extinction under crossed Nicols, and the mineral is said to exhibit parallel extinction; the extinction angle is, by definition, 0°. But if the crystallographic axis does not coincide with an optical axis, the particle will not be at extinction under crossed Nicols when it is aligned with the plane of the polarizer; the extinction angle is the smallest angle through which the particle must be rotated to bring about extinction.

(5) *Elongation sign* also refers to crystalline particles having characteristic elongation. When the direction of elongation is parallel or nearly parallel to the optical axis corresponding to the highest index of refraction, elongation sign is said to be positive. But if the direction of elongation is more nearly parallel to the optical axis corresponding to the lowest index, elongation sign is negative.

Most published methods of petrographic analysis for free silica in industrial dusts are concerned primarily with quartz. However, a general petrographic method can be utilized to determine other forms of free silica if sufficient knowledge of the physical and optical properties of these forms is available. Lists of such properties may be found in Larsen and Berman[3] and in Lange.[4]

The first two of the above optical properties are most important to the identification of quartz. Quartz has (a) two refractive indices, namely 1.544 and 1.553, and (b) very low birefringence (value of 0.009) resulting in an interference color of about light gray in the particle sizes commonly encountered in industrial dusts. Additionally, quartz particles do not exhibit cleavage and thus are irregular in shape. Although pleochroism, extinction angle, and elongation sign are not of direct value in the identification of quartz, they are helpful in the identification of a wide variety of minerals, thus distinguishing them from quartz (or other form of free silica).

A CONTROL METHOD: Knopf[5] in 1933 suggested petrographic "immersion" examination as a control of a chemical method he developed for determining quartz (with the use of hydrofluosilicic acid). The technique involves checking refractive index by immersing the dust particles "in oils of known refractive indices until . . . the boundary between the grains and the liquid disappears." As Knopf stated: "This condition occurs when a refractive index of the miner-

al is the same as the index of the liquid in which it is immersed." No further details of the procedure are given, except that a petrographic microscope is meant to be used. Knopf indicated that such examination is essential both before and after chemical treatment, and that in certain cases is desirable at intervals during the course of such treatment as well. He believed that petrographic examination failed to identify conclusively particles less than 10 microns in size.

A "MODIFIED" METHOD: A "modified petrographic immersion method" was presented by Ross and Sehl[6] in 1935. This involves counting particles in two separate media—namely, fennel-seed oil having an index of refraction of 1.54, and nitrobenzene having an index of refraction of 1.55. An ordinary microscope equipped with a Whipple disk is used. The method is based on the refractive index of quartz that is perceptible on examination with ordinary light—namely, 1.544—and the principle of "central illumination."

Briefly, the principle of central illumination pertains to the fact that nearly all dust particles are thinner at their edges than at their centers, and thus act as small imperfect lenses when immersed in a liquid having an index of refraction different from that of the particles. A particle having an index higher than that of the liquid tends to focus light from the condenser above its plane of focus, while a particle having a lower index than the liquid has a virtual focus below its plane of focus. Thus when a particle with a higher index than the liquid is brought into focus, and the microscope tube is raised slightly, it brightens; and when the same thing is done with a particle having a lower index than the liquid, that particle darkens.

Suspensions of the dust to be examined are first prepared, one in fennel-seed oil and the other in nitrobenzene, and a proper amount of each is transferred to a Sedgwick-Rafter cell, which is then covered. After a settling time of 30 minutes, the two cells (one containing the dust in fennel-seed oil, the other containing the dust in nitrobenzene) are ready for counting.

All the particles in a fixed area subtended by the Whipple disk are counted, as well as those which brighten when the microscope tube is raised slightly above focus. As explained by the authors, in fennel-seed oil (refractive index = 1.54) the particles which brighten are those "of quartz plus particles which have a higher refractive index than quartz"; in nitrobenzene (refractive index = 1.55) the brightening particles are "only those which have a higher refractive index than quartz." The percent of brightening particles in each medium is calculated, and if F is the percent which brightens in fennel-seed oil, and N is the percent which brightens in nitrobenzene, then: percent quartz by particle count = F-N.

A means by which all counted particles are assigned their "due weight," depending upon particle size, allows the percent quartz by weight to be calculated.

The optical setup in this method is the same as that used in the standard light-field counting of impinger dust samples; a 7.5X eyepiece and a 16-mm. objective are used. However, the authors point out that a microscope of higher power can be used for very fine dusts.

Advantages of the Ross and Sehl method are that it is rapid and simple, compared to general petrographic methods, and does not require a petrographic microscope, while being "reasonably accurate" (to quote the authors). It is suitable for particles less than 10 microns in size. However, it has been criticized[7,8] for its utilizing only one optical property (index of refraction with ordinary light). Although one might suppose otherwise from reading the title of the article introducing the method ("Determination of Free Silica . . ."), it is suitable only for the determination of quartz and not other forms of free silica. Its greatest limitation (realized by the authors) is that it does not distinguish between quartz and other minerals whose refractive indices fall within the range of 1.54 to 1.55, such as plagioclase feldspar. Although the authors minimize this point with the statement that "in ordinary dust analyses these other minerals do not occur in amounts sufficient to cause appreciable error," exception to this statement has been taken by Goldman[7] who cites an actual case in which use of the method could have resulted in gross error.

A GENERAL METHOD: Williams[9] presented a general method for the petrographic

analysis of industrial dusts in 1937, giving particular attention to the identification of particles in the respirable sizes—below 10 microns. He noted that in this range about the only optical properties that could be used were indices of refraction, birefringence, and extinction angle. His method also involves immersion examination of the particles, but in plane-polarized light; several immersions in different index liquids (liquids with known indices of refraction) may have to be made for a single dust. A petrographic microscope with magnifications in excess of 2000 times, and a series of index liquids ranging from 1.420 to 1.770 by hundredths, are recommended. (Such index liquids may be prepared by mixing pure liquid compounds of known refractive index in a variety of ways; for example, see the recommendations of Kunz and Spulnik[10] for means of covering most of this range, and Lange[4] for a long list of liquids of known index.)

Refractive index is determined with the analyzer out of the optical system, observation being made of the "Becke line" effect, which is essentially the same as that of central illumination described above.

In the determination of quartz, an index liquid of 1.540 is used first. The main advantage of this is that quartz has indices higher than 1.540, while the indices of potash feldspar and certain soda-lime feldspars, with which quartz is often associated, are below this value. Thus quartz can be readily distinguished from these feldspars.

Williams recommends particle counting in the size range of less than 10 microns as a means of getting quantitative results with the method. Percentages by count of each mineral present may then be expressed. For this, a grid is used in the eyepiece of the microscope.

The method is subject to two main limitations:

(1) There is a lower limit of size beyond which particles cannot be identified. This depends to a great extent upon birefringence, but also upon other factors. The lower particle-size limit for minerals with very low birefringence, such as quartz, is about two microns; for minerals of very high birefringence, such as calcite, the lower limit is about one micron. However, these limits can be lowered somewhat by the use of monochromatic light of short wave length.

(2) There are a few minerals with similar optical characteristics which cannot be distinguished from one another in sizes below 10 microns. An example of this difficulty is that of quartz with a soda-lime plagioclase feldspar (oligoclase).

The outstanding feature of Williams' method is that it can be applied to the identification of a wide variety of minerals including quartz and other forms of free silica. Success depends to a considerable extent upon the skill of the analyst, who must use judgment in proceeding from one step to the next, and in drawing conclusions. Thus, training and experience are necessary for reliable results to be expected.

DARK-FIELD METHODS: Foster and Schrenk[11] devised a method for the petrographic determination of quartz which is especially suited to dusts of very fine particle size. With dark-field illumination and a 1.56 index liquid, quartz particles as small as about 0.3 micron were visible. The authors report that, with these conditions, quartz particles and others of similar index appear as faint blue to gray without a halo, while transparent particles of different index show brighter colors with a halo, and opaque particles are a peculiar shade of bright orange. Thus in use of the method, faint blue to gray particles are counted and related to total particle counts to determine percent quartz by number. With certain assumptions, percent quartz by weight may also be estimated.

Since the method is based mainly on refractive index, it is subject to the same criticism that has been directed toward the method of Ross and Sehl (see above). A variety of minerals with an index in the approximate range of 1.53 to 1.59 may interfere and be included as quartz. However, a maximal value of the amount of quartz in a dust can be determined. The authors emphasize that the method may result in high values for quartz, but that it should not give low values. If no quartz is found, there is reportedly less than 1% actually present.

Crossmon[12] has described a dark-field method for the determination of quartz which requires index liquids exactingly prepared to have the same indices as quartz,

that is, 1.544 and 1.553. Examination with both ordinary and polarized light may be made. To produce the latter, a "cap analyzer" may be placed over the eyepiece of an ordinary microscope. Of particular significance is the finding that, immersed in a 1.544 index liquid, quartz particles will shift in color from predominantly blue to predominantly red, or vice versa, when the cap analyzer is rotated 90°. To identify quartz particles as small as one micron, Crossmon recommends this means.

A PHASE MICROSCOPE METHOD: Crossmon[12] has also studied quartz particles with the dark-contrast phase microscope, and reports that they exhibit characteristic appearances depending on the index liquid in which they are immersed and on whether or not polarized light is used. For example, with a 1.544 index liquid and polarized light, quartz particles oriented for the 1.544 index are blue with a bright red diffraction fringe, while those oriented for the 1.553 index are blue with a yellow fringe. Thus quartz particles can be identified under these conditions by a change in the color of a diffraction fringe from red to yellow, or vice versa, when the plane of polarized light is rotated 90°. With the phase microscope, Crossmon has been successful in identifying quartz particles as small as two microns.

X-ray Diffraction

THE PRINCIPLE of analysis by x-ray diffraction is that every crystalline substance when placed in finely divided form in a beam of monochromatic x-radiation gives rise to a *diffraction pattern* which is unique. This diffraction pattern is the result of radiation being diffracted in different directions with different intensities and is governed by the nature and arrangement of atoms in the substance. As recorded on photographic film, it consists of a series of lines which have definite relationships to one another. The same crystalline substance always gives rise to the same diffraction pattern, whether other crystalline substances are present or not. With a mixture of crystalline substances, the resultant pattern consists of all the patterns of the crystalline components. The resolution of such a complex pattern into its constituent parts is what is done in analysis by x-ray diffraction to determine what substances are present. If the relative densities of selected strong lines of a substance (that is determined to be present in this way) are compared with those of the same substance in a mixture of known composition, the analysis may be placed on a quantitative basis.

A QUALITATIVE METHOD: Bale and Fray[13] in 1935 explained how they applied x-ray diffraction to the determination of quartz in industrial dusts. The dust had to be finely ground, and then it was placed in a capillary glass tube. Filtered x-radiation from a molybdenum-target x-ray tube was passed through the contents of the capillary tube, and the diffraction pattern was recorded on photographic film. This was visually compared with the pattern obtained from pure quartz sand to get qualitative results. Accurate comparisons of line densities to get quantitative results apparently had not been made by the authors to that time, although they were aware that such could be done.

A QUANTITATIVE METHOD: Clark and Reynolds[14] developed an x-ray diffraction method for quantitatively determining quartz (and other crystalline substances) in industrial dusts. The method incorporates an *internal standard* in the unknown dust sample. (The authors got the idea for such a standard from its use in ultraviolet spectroscopy.) The standard consists of a pure crystalline powder, known not to be present in the dust being examined, and this is added to the sample in a definite ratio. The x-ray diffraction pattern is then registered on photographic film by a suitable apparatus, and the ratio of the density of a line of the substance which is sought, such as quartz, to that of a nearby line of the standard is measured photometrically. The percent of sought substance is then read from a curve on which this ratio has been plotted against percent for a series of known mixtures.

The authors used fluorite (CaF_2) as the internal standard in determining quartz. A circular reflection-type camera served for recording the diffraction pattern, and exposure time varied from one to six hours, with dusts having the lowest percentages of quartz requiring the longest exposures. The specimen under examination was in the shape of a wedge, formed by pressing finely

ground material. To reduce quartz to the required fineness, 24 hours of grinding in a steel-ball mill was required of material that had already passed a 200-mesh screen. A microphotometer recording photographically was used for the photometric measurements.

The authors state that the smallest amount of quartz that could be positively identified was about 1%, with accurate measurements only above 4%. "The method is certainly not to be recommended for traces." Interference in determining low concentrations was caused by a multiplicity of lines of substances other than quartz which were present in larger amounts. The accuracy of the method was considered to be within 5%, based on the absolute amount of quartz present.

ELABORATION AND TESTING: Ballard, Oshry, and Schrenk[15] elaborated upon the internal-standard method of determining quartz by x-ray diffraction—originally presented by Clark and Reynolds. They also used an internal standard of fluorite, comparing the 3.35-angstrom line of quartz with the 3.16-angstrom line of fluorite. However, they used a slit to collimate the x-ray beam, instead of pin holes as used by Clark and Reynolds; thus they were able to introduce more sample into the beam and reduce exposure times to a maximum of two hours. They made determinations using an electron-type x-ray tube and also using an ion-type x-ray tube.

The method was tested with 35 synthetic samples containing many different minerals, and quartz in known added amounts ranging from 0.59 to 78.6%, which amounts were unknown to the analyst. Results were better with use of the ion-type x-ray tube. With this tube, error, in percent of the absolute amount of quartz present, ranged from 2% to 11% and averaged about 7% for quartz contents above 3%; when quartz was present to the extent of only about 2%, error was as high as 31% (namely, 0.77% quartz was recorded when the actual value was 0.59%). The authors concluded that "the method is satisfactorily accurate for most purposes, particularly for industrial hygiene studies, and the time required for an analysis is not considered excessive."

IMPROVEMENT: To eliminate many interferences of lines of various minerals in the two-line comparison of quartz determination by x-ray diffraction, Ballard and Schrenk[16] developed a method in which either of two internal standards—calcium fluoride or nickel oxide—can be used. They chose four lines of quartz and five of the standards (two of CaF_2, three of NiO), and plotted 20 analytical curves, each involving a separate ratio, any one of which could be used.

In practice, a dust sample has to be run in the diffraction apparatus to determine qualitatively what minerals are present; then the standard (either CaF_2 or NiO) is chosen so that one of its lines can be compared without interference with one of the four lines of quartz. This allows the internal-standard method to be used on a wide variety of dusts where heretofore there had been serious interferences.

NEWER TECHNIQUES: Recognizing that many difficulties in x-ray diffraction techniques utilizing photographic film were related to the accurate determination of line densities, Klug, Alexander, and Kummer[17] adapted the Geiger-counter spectrometer for directly measuring intensity of the diffracted x-rays, thereby eliminating the use of film and the necessity of photometric measurements. Their method is "essentially the internal standard technique of Clark and Reynolds modified for use with the recording Geiger-counter spectrometer," and results of tests with the method in determining quartz were good. Above 10% quartz, the result was usually (five times out of seven) within 7% of the absolute value. Klug[18] later reported on further developmental work with the technique; using a newer-model spectrometer and known mixtures containing quartz, his results showed a high level of reproducibility.

Kay[19] and Schmelzer[20] have heartily approved use of the Geiger-counter spectrometer for quartz determination. The former emphasizes the importance of proper sample preparation with an internal standard, and with or without binder; the latter promotes a "direct reading" method which requires no internal standard but thus has limitations related to absorption of diffracted x-rays by compounds in the sample. Both claim rapidity in analysis. Schmelzer reported only one-half to one hour for a single determination, excluding time for

preparation of the sample, with accuracy paralleling that of Klug, Alexander, and Kummer.[17]

ADVANTAGES AND DISADVANTAGES: The major advantage of analysis by x-ray diffraction is that quartz (and other crystalline substances) can be identified positively, even in particle sizes well below two microns—a range in which petrographic analysis fails. In fact, the use of x-ray diffraction as an analytical tool requires that the dust be very fine; thus it can be applied to fine air-borne dust as well as that deposited in human lung. According to Berkelhamer,[21] who made analyses for quartz in lung tissue, x-ray diffraction is rapidly becoming the "method of choice in silicosis research." Other advantages are that it can be conducted with minute amounts of material, and that after examination the sample may be used for further analysis, since it is not destroyed nor is its mineralogical composition changed. The major limitation is that elaborate and expensive apparatus is required. Also, x-ray diffraction does not detect amorphous materials, although certain forms of free silica which have been considered to be amorphous have been found to give diffraction patterns.[21] Based on numerous favorable reports, it appears that x-ray diffraction is developing to be a reliable and accurate tool in analysis for crystalline substances. Its popularity in determining quartz in industrial dusts should steadily increase.

McLaughlin, and Blatz[22] have illustrated the potential health hazard of finger burn associated with x-ray diffraction equipment.

Fusion

A METHOD designed to differentiate free silica from silicates and other fusible materials, by fusing the latter and causing them to form spheres, has been presented by Salazar and Silverman.[23] The method is based on the relatively high fusion temperatures of quartz and various other forms of free silica, as compared to other minerals.

The dust sample is passed through a controlled acetylene-air flame and through a steel tube into which the flame extends with wall temperature of about 1500°C; the sample is then collected by electrostatic precipitation and a portion removed to a microscope slide for evaluation by particle counting. This is done with high-dry or oil-immersion magnification, without index liquid, the non-spherical particles (those that did not fuse) being taken to be quartz and other forms of free silica. The result may then be expressed on a count basis. If a percent by weight is desired, a particle-size analysis must be made.

The method was tested on 23 minerals and only barite, garnierite, and zircon were found to interfere, that is, these three minerals did not fuse well and thus could be mistaken for free silica when actually they contain none. Other possible interfering substances are a series of refractories—including corundum, magnesia spinel, and silicon carbide; although these were not tested, it was judged they would interfere because of their high melting points. All forms of free silica tested—quartz, flint, opal, and tripoli—did not fuse appreciably; it was reasoned that this would be the case also with cristobalite and tridymite, which have melting points above that of quartz.

Samples of unknown industrial dusts were analyzed by the method, and results compared with those obtained by petrographic analysis. There was good agreement in nine out of ten cases, with barite interfering in the exception. Diatomaceous earth constituted one of the successfully analyzed samples.

If interfering substances are suspected, immersion in a single index liquid is usually all that is necessary for *petrographic* identification to be carried out since the refractive indices of all found interfering substances are greater than those of quartz.

The apparatus includes supplies of compressed air and acetylene, flowmeters for controlling these gases, electrical precipitating equipment, and other devices. An ordinary microscope is required for counting, but if interfering substances are suspected, a petrographic microscope may also be necessary. An advantage is that only one microscope slide need ordinarily be examined, even when interfering substances are suspected, whereas several often have to be examined in a general method of petrographic analysis. The method reportedly requires only 15-20 minutes for a complete analysis.

Since no form of free silica was found to

fuse appreciably, it appears that the result of the method may include all forms of free silica as a group. This certainly is of value from certain viewpoints, since (as indicated above) various petrographic methods[6,11,12] for free silica pertain specifically to quartz. Also of considerable import is the thought that certain feldspars (such as oligoclase), which by petrographic analysis cannot be distinguished from quartz in particle sizes less than 10 microns, are apt to fuse and thus not be included in the free-silica result as they tend to be in petrographic analysis.

Differential Thermal Analysis

DIFFERENTIAL thermal analysis, or analysis based on differential thermal effects, involves the detection and measurement of thermal effects other than temperature rise —such as those accompanying loss of water, decomposition, and changes in crystal structure—that may occur when a mineral is heated. Some of these effects are exothermic, some are endothermic, but for a given mineral the effects that take place are characteristic of that mineral with respect to both temperature and magnitude. The effects noted in a mixture will be a combination of the effects of the individual minerals.

Berkelhamer[24] developed a method of differential thermal analysis for the determination of quartz in mixtures of minerals. The method is specific for quartz, and although it was not developed even largely for application to industrial dusts, Berkelhamer suggested such application in special circumstances.

A small sample of the unknown mineral mixture is heated at a constant and rapid rate to about 1000°C and the thermal effects are detected and measured by a differential thermocouple having one junction in the unknown and the other in a "thermally inert" substance (a substance not exhibiting thermal effects such as noted above; example: calcined alumina) which receives the same heat treatment. The differential thermocouple is connected to a recorder, and thermal effects exhibited by the sample during test become evident on a differential-temperature curve, appearing as peaks. Quartz is detected by an endothermic peak at about 575°C, denoting its alpha-beta inversion point (temperature of thermal change in crystal structure); the magnitude of the peak indicates the quantity of heat involved in the change, and thus the amount of quartz present.

To eliminate interferences from other minerals which may also have peaks near this point, the sample is calcined before test at a temperature of 950°C for 15 minutes. It was found that this procedure eliminated practically all interferences from clay, other hydrous minerals, and carbonates, without appreciably affecting the reversible and prompt inversion of quartz.

By means of an area measurement of the recorded peak (determination of magnitude) and reference to a calibration curve, a quantitative determination of the percent quartz in the unknown can be made.

The method requires a different calibration curve for each *particular variety* of quartz—such as potter's flint, quartzite, or ferruginous sandstone—to be determined *quantitatively*. This is due to a different heat change associated with each variety of quartz at the inversion point which results in peaks of different magnitudes, but always at the same temperature. For only *qualitative* analysis, the appearance of an endothermic peak at about 575°C is enough to indicate the presence of quartz (but prior calcination is required in either qualitative or quantitative analysis).

Quantitative determinations with the method gave percentages of quartz which were generally within 5% of the absolute values (care being taken that the variety of quartz was known and the proper calibration curve used).

An advantage of the method is that, for all practical purposes, it is particle-size independent. A quantitative analysis reportedly takes about two hours. Although the author refers to the necessary equipment as "simple," three pages[25] are devoted to drawings of construction details. The apparatus includes furnace, variable transformer (to control furnace heat), galvanometer and recorder, and motor (to drive transformer and recorder), as well as various other parts.

The fact that a different calibration curve is required for each variety of quartz to be determined quantitatively is a distinct disadvantage of the method, limiting its usefulness (practically) to those instances

where only one or a few varieties of quartz are involved and where the analysis of many similar samples will justify the time to obtain calibration curves. (An example of such application pertains to mining, where routine control analyses of ore have to be made.) Thus it seems that industrial hygiene applications of the method would be relatively few. However, differential thermal analysis has been utilized to measure the amount of quartz in impure talc[26] and in the raw materials of artificial grinding abrasives,[27] which determinations certainly are of industrial hygiene significance.

Sedimentation

SEPARATION of minerals by sedimentation in heavy liquids is another means for determination of free silica which is based upon differences in specific gravity. Sartorius and Jötten[28,29] have made use of methods employing this property in determining quartz in industrial dusts. In one method, the residue of a dust sample which has been treated with sulfuric acid is suspended in a liquid of specific gravity 2.66 and centrifuged. Since quartz has a specific gravity of 2.65, it should remain suspended while all constituents with specific gravities greater than 2.66 are deposited. Then if the material not deposited is collected and centrifuged in a liquid of specific gravity 2.64, quartz should be deposited. Of course with the quartz will be included any other substances present in the acid residue which have specific gravities in the range of 2.64 to 2.66. Thus the method is not truly specific and the quartz isolated may not be pure. However, the purity can be checked in other ways, such as petrographically. The authors found mixtures of acetylene tetrabromide and ethylene bromide to be suitable as the heavy liquids, and the method of value in analyzing dusts from steel works.

Separation by sedimentation has apparently not been widely applied to industrial dusts. Difficulties arise with small particles, which require very high centrifugal velocities and may flocculate.[23]

Summary

THE principles and salient features of several distinctly significant physical methods for determination of free silica in industrial dusts are presented. These are of particular value in industrial hygiene because they are applicable to dusts of fine particle size, such as may have settled or been collected from industrial atmospheres. Petrographic analysis, which in its application to industrial dusts is based mainly on determination of the optical properties of minerals, and analysis by x-ray diffraction have been best received. The latter is most prominent. Other methods employ fusion, thermal change in crystal structure (differential thermal analysis), and sedimentation as bases for separation. Most of the methods pertain specifically to quartz and not other forms of free silica, but means are indicated whereby other forms may be determined separately or included with quartz. Weaknesses as well as advantages of the various methods are pointed out so as to stimulate further research.

References

1. DOYLE, H. N., TRASKO, V. M., GAFAFER, W. M., and MILLER, S. E.: Accomplishments in the Epidemiologic Study of Silicosis in the United States. *AMA Arch. of Indust. Health*, 12:48-55, (July) 1955.

2. DURKAN, T. M.: The Determination of Free Silica in Industrial Dust. *J. Indust. Hyg. & Tox.*, 28:217-228, (September) 1946.

3. LARSEN, E. S., and BERMAN, H.: The Microscopic Determination of the Nonopaque Minerals. *U.S. Geolog. Survey, Bulletin* 848, (Second Edition) 1934.

4. LANGE, N. A. (Editor): Handbook of Chemistry (Eighth Edition). Handbook Publishers, Inc., Sandusky, Ohio, 1952.

5. KNOPF, A.: The Quantitative Determination of Quartz ("Free Silica") in Dusts. *Pub. Health Rep.*, 48:183-190, (February 24) 1933.

6. ROSS, H. L., and SEHL, F. W.: Determination of Free Silica—Modified Petrographic Immersion Method. *Indust. & Eng. Chem., Anal. Ed.*, 7:30-32, (January 15) 1935.

7. GOLDMAN, F. H.: Methods for the Determination of Quartz in Industrial Dusts. *Pub. Health Rep.*, 52:1702-1712, (November 26) 1937.

8. BLOOMFIELD, J. J., HATCH, T., and WILLIAMS, C. R.: Review and Discussion of Methods of Analyzing Industrial Dusts. *Am. Pub. Health Assoc., Eighth Annual Year Book*, 1937-1938, pp. 85-90 (Supplement to *Am. J. Pub. Health*, Vol. 28, February, 1938).

9. WILLIAMS, C. R.: The Petrographic Method of Dust Analysis. *J. Indust. Hyg. & Tox.*, 19:44-52, (January) 1937.

10. KUNZ, A. H., and SPULNIK, J.: Standard Liquids for the Microscopic Determination of Refractive Index. *Indust. & Eng. Chem., Anal. Ed.*, 8:485, (November 15) 1936.

11. FOSTER, W. D., and SCHRENK, H. H.: Petrographic Identification of Atmospheric Dust Particles. *U.S. Bureau of Mines, Report of Investigations* 3368, (January) 1938.

12. CROSSMON, G.: Determination of Free Silica by Dispersion Staining Microscopical Methods. *Am. Indust. Hyg. Assoc. Quarterly*, 12:117-120, (September) 1951.

13. BALE, W. F., and FRAY, W. W.: A Method for the Analysis of Dust Samples Employing X-ray Diffraction—A Preliminary Report. *J. Indust. Hyg.*, 17:30-32, (January) 1935.

14. CLARK, G. L., and REYNOLDS, D. H.: Quantitative Analysis of Mine Dusts—An X-ray Diffraction Method. *Indust. & Eng. Chem., Anal. Ed.*, 8:36-40, (January 15) 1936.

15. BALLARD, J. W., OSHRY, H. I., and SCHRENK, H. H.: Quantitative Analysis by X-ray Diffraction—1. Determination of Quartz. *U.S. Bureau of Mines, Report of Investigations* 3520, (June) 1940.

16. BALLARD, J. W., and SCHRENK, H. H.: Routine Quantitative Analysis by X-ray Diffraction—1. Photometric Procedure; 2. Analytical Method. *U.S. Bureau of Mines, Report of Investigations* 3888, (June) 1946.

17. KLUG, H. P., ALEXANDER, L., and KUMMER, E.: X-ray Diffraction Analysis of Crystalline Dusts. *J. Indust. Hyg. & Tox.*, 30:166-171, (May) 1948.

18. KLUG, H. P.: Quantitative Analysis of Powder Mixtures with the Geiger-Counter Spectrometer. *Anal. Chem.*, 25:704-708, (May) 1953.

19. KAY, K.: Rapid Quartz Analysis by X-ray Spectrometry. *Am. Indust. Hyg. Assoc. Quarterly*, 11:185-194, (December) 1950.

20. SCHMELZER, L. L.: A Rapid X-ray Diffraction Method for the Determination of Quartz in Industrial Dusts. *AMA Arch. of Indust. Hyg. & Occup. Med.*, 3:121-128, (February) 1951.

21. BERKELHAMER, L. H.: X-ray Diffraction—An Important Tool in Pneumoconiosis Research—And a New Method of Tissue Analysis. *J. Indust. Hyg. & Tox.*, 23:163-175, (May) 1941.

22. MCLAUGHLIN, J. E., JR., and BLATZ, H.: Potential Radiation Hazards in the Use of X-ray Diffraction Equipment. *Am. Indust. Hyg. Assoc. Quarterly*, 16:108-112, (June) 1955.

23. SALAZAR, A., and SILVERMAN, L.: A New Method for the Determination of Free Silica in Industrial Dusts. *J. Indust. Hyg. & Tox.*, 25:139-148, (April) 1943.

24. BERKELHAMER, L. H.: Differential Thermal Analysis of Quartz. *U.S. Bureau of Mines, Report of Investigations* 3763, (July) 1944.

25. BERKELHAMER, L. H.: An Apparatus for Differential Thermal Analysis. *U.S. Bureau of Mines, Report of Investigations* 3762, (July) 1944.

26. SCHEDLING, J. A.: Uber die Differentialthermoanalyse quarzhaltiger Stäube (On the Differential Thermal Analysis of Quartz-containing Dusts). *Staub*, 30:243-244, (December 15) 1952.

27. SCHEDLING, J. A., and WEIN, J. B.: Quarzgehaltsbestimmung an Schleifscheibenstäuben mittels der Differentialthermoanalyse (Determination of Quartz Content of Dusts from Grinding Wheels by Means of Differential Thermal Analysis). *Staub*, 31:13-18, (March 15) 1953.

28. SARTORIUS, F., and JOTTEN, K. W.: Weitere Untersuchungen zur Frage der Silicatanalyse bei Gewerbestauben (Further Investigations on the Question of Silica Analysis of Industrial Dusts). *Zentralblatt fur Gewerbehygiene und Unfallverhutung*, 21:65-69, 1934.

29. SARTORIUS, F., and JOTTEN, K. W.: Neue Untersuchungen zur Quarz - und Serizitanalyse in Gewerbestauben (New Investigations on Quartz and Sericite Analysis in Industrial Dusts). *Archiv fur Hygiene und Bakteriologie*, 115:135-151, 1935.

Regulations Governing Use of Radiation

THE NEW YORK STATE Department of Labor and the Department of Health have adopted regulations designed to protect the workers most likely to be exposed to radiation hazards. Industrial Code Rule No. 38 covers about 150,000 workers in industries where exposure to radiation is possible. The Sanitary Code of the Health Department is designed for the protection of personnel in hospitals, dental offices, and similar establishments. The codes are designed to cover most of the peacetime applications of radiation.

The Collection of Submicron Particles by Electrostatic Precipitation

DAVID A. FRASER, M.S.
United States Public Health Service
Department of Health, Education and Welfare
Occupational Health Field Headquarters, Cincinnati

IT HAS BEEN reported that a separation of particle sizes occurs when a polydisperse aerosol is collected by electrostatic precipitation.[1,2] It has been suggested that the larger air-borne particles are most readily collected and therefore the efficiency of precipitation decreases as the size of the particles decreases. On the other hand, recent experiments in this laboratory have indicated that, in the submicron range, smaller particles are collected with greater efficiency than the larger ones. A search of the literature yielded many contradictory opinions, but no rigorous theoretical treatment which might explain the behavior of small as well as large particles in an electrostatic field. It has been our purpose to examine experimentally the effect of particle size on efficiency of collection in the electrostatic precipitator and to correlate our findings with existing theories.

Experimental

THE ELECTROSTATIC precipitator described by Hosey and Jones[3] (Fig. 1) was chosen for most of our experiments for two reasons. First, it affords easy placement of electron microscope screens. Second, the ionizing discharge takes place in a limited area near the entrance of the precipitator and not along the entire length of the tube as in more conventional wire in cylinder types; thus, any tendency toward selective precipitation of particles according to sizes should be more apparent due to the simplified mechanism of collection. The precipitator was operated at the voltage recommended for normal use (12,000 V) but at the slightly reduced air flow of eight liters per minute. Four electron microscope screens were attached to the glass slide collecting plate at positions 3 cm. apart beginning 1 cm. behind the ionizing electrode. Scotch tape with adhesive on both sides was used to hold the screens in position.

Dust clouds of various materials were blown into a large settling flask and then drawn into a 40-liter bell jar from which they were sampled with the precipitator. The following dusts were used: (1) V_2O_5—c.p. vanadium pentoxide which had been ground in a ball mill for six hours; (2) SiO_2—washed sand which had been ground in a ball mill for 12 hours; (3) Granite dust —previously air-borne material taken from the centrifugal type dust collectors in the ventilation systems used in the granite industry; (4) Cobalt blend—an intimately ground mixture of metallic cobalt and certain metallic carbides used in the cemented

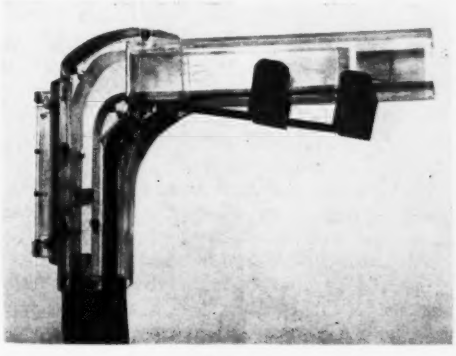


Fig. 1.
The electrostatic precipitator sampling head described by Hosey and Jones.[3] Shown is the built-in flowmeter (A), the ionizing electrode wire (B), and the grounded brass spring clips (C) (partially disengaged) which hold the glass collecting plates in position.

TABLE I.
MEDIAN SIZES, IN MICRONS, FOUND AT DIFFERENT POSITIONS IN THE WIRE & PLATE PRECIPITATOR

Position	V_2O_5	SiO_2	Granite	Co Blend	NaCl
1	.09	.03	.20	.08	.08
2	.13	.06	.12	.09	
3	.17	.08	.22	.12	
4	.24	.09	.30	.13	.09
MF	.20	.10	.21	.13	
Brushed Sample	.17	.09	.19	.11	.09

MF = molecular filter

tungsten carbide industry; (5) Sodium chloride condensation nuclei—produced in the LaMer-Sinclair type aerosol generator.

The sampling of the dust cloud was continued until a deposit was visible on the first electron microscope screen. This screen was removed and sampling continued until the second screen had collected a visible deposit. This screen was removed and the process repeated until all four screens had collected sufficient sample for a particle-size analysis. A simultaneous sample of the dust cloud was taken with the molecular filter and treated by a method described previously.[4] A specimen of the parent dust (not airborne) was prepared by brushing on an electron microscope screen with a soft camel's hair brush. The six samples of each dust thus collected were photographed, using the electron microscope, and size analyses made of the resulting pictures.[4] Table I shows a tabulation of the median sizes obtained from each sample. It will be noticed that in each case the material collected at position four had a larger median size than that collected at the entrance of the precipitator. The molecular filter sample is taken to represent the true over-all size of the dust without any selectivity of collection. The reasonable agreement between the molecular filter sample and the brushed specimen prepared from the parent dust seems to substantiate this assumption.

Fig. 2 shows a set of these data plotted on log-probability paper in the usual manner for particle-size analysis. While this particular example is one of the more obvious, it is nevertheless quite typical of the data obtained. It will be noted that while the median size changes for each collecting position of the precipitator, the deviation remains nearly constant. This is quite interesting and indicates that there is no sharp cut-off or precipitation by size. At position four the range of particle sizes is the same as at position one and some of the smallest particles are still air-borne (25% $<0.1\mu$). From this chart the number of particles below a given size can be easily read, and it is seen that for position one, 82% of the particles are smaller than 0.2 μ, the seldom attained theoretical limit of resolution of the optical microscope. The size distribution of the particles collected at all of the collecting positions is, in fact, dominated by high percentages of particles which are below the resolving limit of the optical microscope. Thus a particle-size analysis made using this instrument would not give a true picture of the precipitation process. Since the majority of all particles are precipitated near the entrance of the precipitator, the impression might be given that the larger particles were more easily collected. To demonstrate this experimentally, a number of the same electron microscope screen specimens which were photographed were permanently mounted in balsam on a microscope slide, and a particle-size analysis was made using the optical microscope equipped with a 97X oil-immersion objective. Table II shows

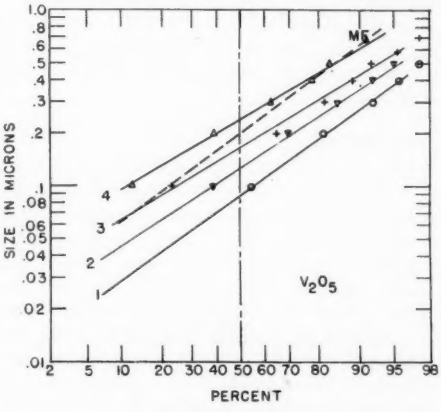


Fig. 2.
Plot of typical data on log-probability paper showing the variation of the median size and the uniformity of the deviation (slope) obtained at four different sampling positions in the electrostatic precipitator. The dotted line shows the distribution obtained by the molecular filter technique.

TABLE II.
COMPARISON OF MEDIAN SIZES, IN MICRONS, OBTAINED WITH ELECTRON AND OPTICAL MICROSCOPES

V_2O_5			Granite		
Position	E.M.	Optical	Position	E.M.	Optical
1	.09	.31	1	.20	.25
2	.13	.27	2	.12	.26
3	.17	.32	3	.22	.24
4	.24	.35	4	.30	.31
MF	.20	.33	MF	.21	.28

MF = molecular filter EM = electron microscope

a comparison of the median diameters obtained by the two techniques. It is seen that no trend is apparent in the optical series.

For comparison purposes, some tests were made using the conventional wire-in-cylinder precipitator. In this case it was found that the more intense field near the cylindrical aluminum collecting electrode was distorted by the metallic electron microscope screens. The dust collected was deposited almost exclusively directly over the wires of the screens, rather than on the Formvar substrate, making observation in the electron microscope impossible. To avoid this, the Formvar screens were coated with a very thin film of chromium by vacuum evaporation and were then fastened to a square of shim brass cut to serve as a liner for the aluminum cylinder by small brass spring clips which made contact with the chromium coated film on the Formvar. The substrate of chromium caused some loss of resolution in the electron microscope due to the background scatter of electrons, but the resolution was still sufficient for our purpose (200 A° or .02 μ) and an acceptable sample could be collected in this manner. This precipitator was operated under the same conditions as the Hosey-Jones precipitator. Table III gives the median diameters found at the same collecting positions as in the Hosey-Jones precipitator. Again there seems to be a tendency for the smaller particles to be collected nearer the entrance of the precipitator although the effect is not nearly so pronounced as in the previous instrument. In this case, also, the deviations at the various collecting positions remained constant, indicating again that some of the small particles penetrated to the final screen, while some of the larger particles were precipitated on the first screen.

Theory

THE CORONA discharge consists of an electrical current carried by ions produced by the secondary ionization resulting from the impacts of rapidly moving ions with the gas molecules. This secondary ionization takes place within the corona itself where part of the energy of collision is converted into the luminous effect of the discharge. The dark space between the luminous corona and the collecting electrode and comprising better than 95% of the cross sectional area of the precipitator tube is the region filled with ions of the same charge as the ionizing electrode and being accelerated toward the collecting electrode of opposite charge. It is in this area that the charging of dust particles occurs by collision with these ions. The nature of the ions formed by secondary ionization is quite complex and the following ions have been identified by the techniques of mass spectroscopy as being present: N_4+, N_3+, N_2+, $N+$, N, $N+++$, $N++$, N_2-, $N-$, O_2+, $O+$, $O++$, O_3+, O_2-, $O-$, also masses 72, 80, 100, 125, 155, 160, $NO+$, NO_2+, N_2O+, and masses 56, 76, 96, 128, 140, 168, 200.[5]

The flow of ions toward the oppositely charged collecting electrode gives rise to what has been termed the "electric" or "ionic" wind due to the transfer of momentum from the moving ions to the gas molecules. Although this wind effect may help to move the charged particles toward the collecting electrode, the main effect is that of producing turbulence and an equalization of particle concentration between the electrodes.[6] Such turbulence will be a strong factor in opposition to any tendency toward a selective precipitation of particles according to size.

TABLE III.
MEDIAN SIZES, IN MICRONS, FOUND AT DIFFERENT POSITIONS IN THE WIRE IN CYLINDER PRECIPITATOR

Position	V_2O_5	SiO_2	Granite
1		.07	.20
2	.14	.09	.12
3	.26	.09	.22
4	.24	.10	.30
MF	.22	.09	.21
Brushed Sample	.17	.11	.19

MF = molecular filter

Since the total charge received by a particle is determined by the number of collisions with carrier molecules (ions), it is not an instantaneous affair. The charge acquired in a given time "t" can be calculated as

$$Q = Q_o\left[\frac{\pi ti/E}{1 + \pi ti/E}\right]$$

where Q_o is the maximal charge, i, the current density and, E the potential gradient.[6,7,8] This equation has been verified by Fuchs[9] for particles 0.5 to 3.0 μ in diameter. Under normal conditions, 90% of the maximal charge is attained in less than 0.1 sec.,[10] and we may therefore assume for the rest of this discussion that the particles remain in the field of the electrostatic precipitator for sufficient time to approach their maximal charge. Certainly, this condition can be obtained by proper regulation of the flow rate of the sampling apparatus. It has been shown by Millikan[11] that small, charged particles moving in a gas under an electrostatic field obey Stokes law; thus $F=6\pi\eta av$ where F is the force necessary to give the particle a constant velocity V, a is the radius of the particle, and η is the coefficient of viscosity of the gas. Therefore, $k = \frac{e}{6\pi\eta a} =$ mobility in cm/sec/volt where e = charge on particle. However, when a becomes so small that it is comparable with the ionic free path Cunningham's correction must be applied and we get

$$k = \frac{e}{6\pi\eta a}\left(1 + A\frac{L}{a}\right)$$

L = mean free path of air molecules = 10^{-5} cm = 0.1 μ

A = constant = 0.874 (Millikan[11])

Thus as a approaches $0.1/\mu$ this correction amounts to a factor of 2 (approx.) and for a= .043 the correction would be a factor of 3. Thus, for a unit charge, as a decreases the velocity of a particle toward the collecting electrode would be expected to increase significantly. A more rigorous development of this is given by Loeb.[12] He shows that the close similarity of this equation with the theoretically derived "small-ion" form of the Langevin equation[13] leaves little doubt as to the correctness of each of these.

There are two mechanisms possible for the charging of particles in the field of the electrostatic precipitator. The first of these is the purely random collision with ions due to the kinetic effect. Deutsch[14] has shown that the maximal charge that a particle can assume in this manner is proportional to the radius and will be equal to $Q = 2 \times 10^6 r$ under normal operating conditions.

TABLE IV.
VARIATION OF MIGRATION VELOCITY WITH PARTICLE SIZE

Particle Diameter, in microns	Number of Elementary Charges	Migration Velocity (cm/sec)
0.1	10	8.2
0.25	25	4.6
0.5	50	3.5
1.0	105	3.3
2.5	655	7.9
5.0	2620	15.0
10.0	10470	30.0
25.0	65500	73.0

If the dielectric constant of the particles is lower than that of the air, then the electrical lines of force will converge on the particle and ions following the lines of force will be led on a collision path to the particle. When the particle becomes charged, however, the lines of force are bent away, making collision unlikely. The maximal charge which can be attained by the particle in this manner is given by Ladenburg:[15]

$$Q = e^{-1}\left[1 + 2\ (D\text{-}1)/(D+2)\right] E r^2$$

where D = dielectric constant, and E = external field.

In considering these two equations it is seen that for particles larger than 2 μ in diameter the second is by far the more important, but for smaller particles the equation describing the random collisions of kinetics predominates. If each of these equations is combined with Stokes Law and the Cunningham correction, the calculations can be made which are summarized in Table IV.

Thus, it is seen that as the particle size decreases, the acceleration of the particle toward the collecting electrode decreases until a diameter of 1 μ is reached. Decreasing the diameter further increases the speed of collection. If this table is considered along with the Deutsch equation for the collection efficiency of the electrostatic precipitator

$$\eta = 1 - e^{-2WL/SV}$$

(where W = migration velocity, L = electrode length,
S = electrode separation, V = gas velocity)

we would expect the efficiency of collection of submicron particles to increase as the particle size decreases.

Summary

EXPERIMENTAL data are presented which indicate that in the submicron range smaller particles are precipitated more readily than larger particles.

The theory of electrostatic precipitation processes is reviewed and it is shown that the experimental data agree with theoretical predictions.

A comparison is made between results obtained using the electron microscope and the optical microscope to explain the conflicting statements found in the literature.

References

1. DRINKER, P., THOMPSON, R. M., FITCHET, S. M.: Atmospheric Particulate Matter: II. The Use of Electric Precipitation for Quantitative Determinations and Microscopy. *J. of Ind. Hyg.*. 5:162, 1923.

2. DRINKER, P., and HATCH, T.: Industrial Dust, 2nd Ed. McGraw Hill, New York City, 1954.

3. HOSEY, A. D., and JONES, H. H.: Portable Electrostatic Precipitator Operating from 110 volts A.C. or 6 volts D.C. *Arch. of Ind. Hyg. & Occup. Med.*, 7:49, 1953.

4. FRASER, D. A.: An Absolute Method of Sampling and Measurement of Solid Air-borne Particulates. *Arch. of Ind. Hyg. & Occup. Med.*, 8:412, 1953.

5. GLOCKSER and LIND: The Electrochemistry of Gases and Other Dielectrics. John Wiley & Sons, New York City, 1939.

6. MIERDEL and SEELIGER: The Physical Basis of Electrical Gas Purification. *Trans. Faraday Soc.* 32:1284, 1936.

7. DALLEVALLE, J. M.: *Micromeretics.* Pitman Publishing Corp., New York City, 1943.

8. PAUTHENIER, M. M., and MOREAU-HANOT, M.: La Charde des Particules Speriques dans un Champ Ionise. *J. Physique*, 3:590, 1943.

9. FUCHS, PETRJANOFF, ROTZEIG: On the Rate of Charging of Droplets in an Ionic Current. *Trans. Faraday Soc.*, 32:1131, 1936.

10. SEELIGER, R.: The Physics of Electrostatic Precipitation. *Z. Tech. Phys.*, 7:49, 1926.

11. MILLIKAN, R. A.: Some Facts Bearing on the Structure of Atoms, Particularly of the Helium Atom. *Phys. Rev.* 18:456, 1921.

12. LOEB, L. B.: The Fundamental Processes of Electrical Discharge in Gases. John Wiley & Sons, New York City, 1939.

13. LANGEVIN, P.: Une Formule Fondamentale de Theorie Cinetique. *Ann. Chim. Phys.* 5:245, 1905.

14. DEUTSCH, W.: The Movement and Charge of Electrically Charged Particles in a Two Cylinder Capacitor. *Ann. Physik.*, 1922.

15. LADENBURG, R., and TIETZE, W.: A Study of the Physical Processes in the So-Called Electrical Purification of Gases. Part II-The Action of the Electrical Wind. *Ann. Physik.*, 6:581, 1930.

New Research Company

DR. LOUIS MCCABE, formerly Scientist Director for the United States Public Health Service has announced the formation of Resources Research, Inc., a firm of consultants in research and engineering. FREDERICK MALLETTE, a member of AIHA and Executive Secretary of the Committee on Air Pollution Controls and Research Manager of the American Society of Mechanical Engineers, has joined DR. MCCABE in forming the new firm. WILLIAM S. MCCABE, consulting geologist of Casper, Wyoming is also associated with the new company. The organization will handle research and development in geology, mining, industrial wastes, water resources, and the economics and supply of conventional and atomic fuels. It will deal with problems such as fuel sources and their evaluation for power, metallurgy and chemistry; research and engineering in air and stream pollution; water treatment and supply problems; and the development of fuel resource properties. The staff of the new firm will include specialists in chemistry, chemical engineering, geology, physics, economics, and industrial engineering. The aim is to bring together into one organization outstanding men in the highly specialized aspects of these fields, to provide a coordinated, readily available source of engineering and scientific talent for industry and government. The main office of Resources Research, Inc. will be in the Wisconsin Building, 4435 Wisconsin Ave., N. W., Washington 16, D. C., with offices also in New York City at 55 West 42nd Street. In Casper, Wyoming, the address is P. O. Box 1861.

Estimating Airborne Radioactive Particulate Hazards

—A REVIEW OF SAMPLING CRITERIA—

T. J. BURNETT, Health Physics Division
Oak Ridge National Laboratory, Oak Ridge, Tennessee
T. F. HATCH, School of Public Health
University of Pittsburgh, Pittsburgh, Pennsylvania

MANY METHODS of air sampling in current use prevent, rather than permit, a true evaluation of the potential hazard from airborne radioactive particulates. The non-uniformity of exposure of pulmonary tissue can be evaluated only from adequate data obtained by proper sampling. There presently exist several methods by which we are able to sample properly for airborne radioactivity and approach a meaningful interpretation of the hazards present.

Information Needed

A METHOD of sampling airborne radioactivity must provide the following information: (1) the amounts of activity retained respectively in the upper respiratory tract and in the alveolar spaces of the lung, (2) the solubility of retained active material (and in some cases its radiochemical composition), (3) the decay rate and the kind and range of the radiations, and (4) the numbers of the retained individual particles per unit sample volume and their discrete activities, or μc per particle.*

These items of information are needed to determine the following: (a) the total initial body retention, (b) the critical body organ, (c) the dose rates to exposed tissues, (d) the total exposures for the period of inhalation represented by the sample, and (e) the degree of non-uniformity of distribution of tissue exposure.

Only after determining these factors can an evaluation of internal hazard be made by comparison with permissible concentration values and exposure levels. The situation requiring such an evaluation is that in which the air carries particles of some radioactive material. The concentration and size distribution of these particles are unknown. How much is known about the radioactive material will depend on the circumstances, and no information may be available. It is appropriate to examine why the stipulated data is required and how it may be obtained using some air samplers but not others.

Our interest in airborne radioactivity is based on its possible hazard to man. If

Presented at the Fifteenth Annual Meeting of AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, April 28, 1954, Chicago.

*A microcurie, μc, is that quantity of material in which 37,000 disintegrations—occur per second.

TABLE I.
CALCULATED UPPER RESPIRATORY AND ALVEOLAR RETENTION FOR THREE DUSTS

	Size Distribution		% Retained				Equal Number Concentrations in Air				Equal Weight Concentrations in Air			
	$M_{(g)}$	$\sigma_{(g)}$	By Number		By Weight		Relative Amounts By Number		Retained By Weight		Relative Amounts By Number		Retained By Weight	
	μ		UR	Alv.	UR	Alv.	UR	Alv.	UR	Alv.	UR	Alv.	UR	Alv.
A	0.3	2.0	0.37	37.5	18.2	43.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
B	0.3	2.7	2.25	36.2	68.9	19.8	6.1	0.97	35	4.2	0.65	0.104	3.8	0.45
C	0.3	3.66	5.26	34.8	96.1	<2.7	14.2	0.93	1140	<13.2	0.07	0.004	5.3	0.06

TABLE II.
AVERAGE UR AND LUNG DOSE RATES AFTER 1 HOUR EXPOSURE TO STATED CONCENTRATIONS OF DUST A, B, AND C
(1% Active Particles, Sp. Activity = 20 c/gm)

Dust	Dose Rate UR	Lung	Concentrated in Lymph Nodes
Case I: Equal number concentrations in air = 2 x 10^8/m^3			
A = 13 $\mu c/m^3$	0.12 rep/hr	5 mrep/hr	220 mrep/hr
B = 120 $\mu c/m^3$	4.15 rep/hr	21 mrep/hr	950 mrep/hr
C = 2800 $\mu c/m^3$	136.00 rep/hr	67 mrep/hr	3000 mrep/hr
Case II: Equal number concentrations (2 x 10^8/m^3) and assumed constant alveolar retention (12%)			
A = 13 $\mu c/m^3$		1.2 mrep/hr	
B = 120 $\mu c/m^3$		11.6 mrep/hr	
C = 2800 $\mu c/m^3$		295 mrep/hr	
Case III: Equal weight concentrations in air = 1.57 mg/m^3 = 100 mrep/hr submersion dose			
A = 314 $\mu c/m^3$	2.9 rep/hr	120 mrep/hr	5.4 rep/hr
B = 314 $\mu c/m^3$	10.8 rep/hr	53 mrep/hr	2.4 rep/hr
C = 314 $\mu c/m^3$	15.1 rep/hr	7.5 mrep/hr	0.3 rep/hr
Case IV: Equal weight concentrations in particles $< 5\ \mu$ = 1 $\mu c/m^3$			
A = 1 $\mu c/m^3$	9 mrep/hr	0.38 mrep/hr	17 mrep/hr
B = 2.3 $\mu c/m^3$	80 mrep/hr	0.41 mrep/hr	19 mrep/hr
C = 22.7 $\mu c/m^3$	1100 mrep/hr	0.56 mrep/hr	25 mrep/hr

present in sufficient concentrations, distinct external and internal exposure hazards requiring evaluation may be present. External exposure from submersion, or from surface contamination depends directly on the kind, concentration, location, frequency, and persistence of the airborne radioactivity. The amount of external radiation exposure may not provide any indication of the associated hazards of internal exposure. (See Table II.) Since external exposure can be evaluated with sufficient accuracy using standard radiation monitoring instruments and dosimeters, it need not be discussed here.

Character of Hazard

THE INTERNAL exposure hazard results from the inhalation and retention of radioactive particulate matter in the respiratory system and from its subsequent distribution in the body. This hazard will depend on biophysical and biochemical variables in addition to factors listed for external exposure.

A radioactive particle will have the same aerodynamic behavior as an inert particle with corresponding dimensions and density. Thus, we may expect active particles to show the well known dependence of deposition site in the respiratory system on aerodynamic size.** Although a sharp size separation is not made, the particles retained from inhaled air are distributed so that progressively smaller sizes are held up in correspondingly deeper sections of the respiratory system. The differences in deposition mechanism and in subsequent retention lead to a division of particles into two groups. The "upper respiratory" fraction are those which are deposited primarily by impaction on the ciliated epithelium lining the air conducting passageways. The "alveolar" fraction are those which are deposited primarily by sedimentation and diffusion in the estimated 700 million alveoli where respiration occurs.

The efficiencies of both upper respiratory and alveolar deposition vary quite widely with the particle size. Therefore, the size distribution of the airborne particles can be shown to exercise a profound effect on both the absolute and relative amounts of inhaled activity retained. (See Table I.) After deposition, the aerodynamic size is of no further concern and only the activity per particle is important. The activity per particle need bear no relation to the aerodynamic size since particles with the same dimensions may have different specific activities depending on whether they are wholly composed of active material, coated with it, or have only an inclusion of active material.

The inhaled active particles are discrete sources of radiations, deposited at separate initial sites, and are subject to considerable variation in individual activity. The effects of individual particles may be additive to the tissues between their loci and their aggregate effect can be evaluated from the total of the effects of individual particles. The dose rate to an elemental volume of tissue in the vicinity of any given active particle will depend on the amount of activity present, the kind and energy of the radiations emitted and the distances from this elemental tissue volume to as many active particles, including the given one, as are within range of their radiations.

**The work of a number of investigators has been critically reviewed by C. N. Davies in "Dust Sampling and Lung Disease," *Brit. J. of Indust. Med.*, 9:120, 1952, and also by M. Eisenbud in *Arch. of Indust. Hyg. & Occup. Med.*, 6:214, 1952.

The dependence of dose rate on distance from a source particle is due primarily to the inverse square law and also to absorption of the radiation in the intervening layers of tissue. The dose rate in the tissues within range of betas emitted from an active particle may vary through several orders of magnitude within a hundred cell diameters or less. To see this more clearly, one may visualize a series of concentric spherical shells with center at the particle, cutting the adjacent tissue into imaginary layers somewhat like the layers of an onion. The volume of tissue receiving a dose rate in a chosen range between specified upper and lower limits is that volume between the shells at whose respective radii these dose rates occur.

The Particle Problem

THIS widely varying dose rate associated with the multiple islands of exposure around active particles, or the very intense dose rate close to a particle, is the basis for the controversial concept of a "unique particle problem." The question of controversy is whether or not the activity concentrated on particles at their dispersed sites of retention will ultimately cause greater injury than the same total activity uniformly distributed in the whole lung. No conclusive evidence in support on denial of the "particle problem" has yet been reported by biological experimenters. In part, this lack is the result of the difficulties inherent in the preparation and measurement of suitable aerosols, in properly administering them to experimental animals, and in the evaluation of the results. The resolution of this problem also requires that these studies consider and separate the effects of solubility from those of other clearance mechanisms. The air sampling methods so widely used at present are inadequate for detecting and decribing the radioactive content of atmospheres. Thus they cannot provide environmental exposure data for correlation with clinical studies which might resolve this problem.

Since inhaled particulate activity is never uniformly distributed in the lung, an adequate sampling method is always required to provide data for properly estimating the exposures to the separate retention site tissues. (This permits the all important determination of a suitable "non-uniformity" factor such as that found necessary for estimating the exposure to the bones and other organs.) If exposure rates in a certain range of magnitudes are considered potentially significant, the tissue volumes exposed at rates in this range may be calculated for a group of active particles. The total of these volumes can be compared to the total volume of the organ, indicating the degree of non-uniformity of exposure. As an alternate, this total exposed volume can be expressed in terms of the equivalent number of cells affected, on the basis of an average cell volume.

Much more important than the exposure rate at a particular time is the total exposure received by the various specific local volumes of tissue. During the period in which an active particle produces an exposure rate gradient in its vicinity both its source strength and its location are subject to change. Our previous visualization of concentric zones of exposure must now be replaced by a dynamic picture in which the hypothetical shells move through the tissue with the particle and shrink in size.

Radioactive decay to a non-radioactive daughter element represents a decrease of source strength which is exponential with time. If the particle is assumed to be stationary the integrated total exposure to adjacent tissue can be calculated and exhibits the same degree of non-uniformity as the dose rate.

Solubility Effects

THE SOLUBILITY of the particle will result in transport and relocation of its molecules thus reducing the amount of its individual activity. This mode of activity reduction may exhibit a dependence on time which is different from that due to decay. To the extent that the dissolved active material persists in the vicinity of the particle and diffuses outward, the point source is changed and with it the exposure gradient. Solubility will differ with particle diameter and is greater for the smaller alveolar particles which have a greater surface area per gram. Solubility will also differ with the kind of tissue fluid in the environment of the particle. "Insoluble" is only a relative term. In particular, solution by the formation of complex ions with the tissue fluids

is enhanced by an increase of surface area. In the case of alveolar retention there may be a relatively long time available for solvent action. The relative importance of radioactive decay and solubility depends on their comparative rates and the total effect will be the combined result of these reductions in activity.

Upper respiratory particles are discharged to the G.I. tract and subject to solution in the fluids there encountered. Absorption of dissolved active material to the blood from the G.I. tract is frequently small. In comparison, active substances dissolved from alveolar particles are absorbed by the bed of capillary blood vessels so rapidly as to be comparable with the rate of absorption following intravenous injection. Dissolved active material is transported by the blood and relocated by deposition in the organs determined by the metabolism of the body. Therefore, for some combinations of solubility and metabolism, particle borne activity could produce a total exposure to other body organs much greater than that received by the respiratory system.

An obvious reduction in exposure time is achieved with the transport of the total particle by biological mechanisms. The transport mechanisms of the two retention zones are quite distinct. By their beating action, the cilia of the epithelium lining of the upper respiratory passageways begin immediately upon deposition of a particle to move the particle at a rate of as much as 0.25 cm/min toward the G.I. tract.[1] Some time after the deposition of a particle in an alveolus and in response to the degree of irritation it produces there, a phagocytic cell may engulf the particle and migrate with it either into the lymphatic system or along the respiratory epithelium to the ciliary escalator. In the lymphatic system, particles may be filtered out by the lymph nodes and retained.

Evaluation of Hazard

AFTER considering the factors determining internal exposure, it is seen that the collection and study of a sample of airborne activity is required. This sample must provide information on: (1) the amounts of activity retained respectively in the upper respiratory tract and in the alveolar lung, (2) solubility data for these respective amounts (in case of large solubility, a radiochemical analysis may be desirable to see what organs will be affected by relocation and absorption of soluble activity carried by the blood), (3) decay rates and measurements of kind and range of radiations, and (4) the number and activity values of individual particles (to estimate non-uniformity of exposure).

It follows that much data obtained by the standard methods of air sampling in current use prevents rather than permits an evaluation of the true hazard. It is obvious that a "total" sample whether taken with a filter, precipitator, or otherwise gives no data on respiratory zone retention, and thus makes it impossible to establish the percent retentions for the size distribution of particles in the air and the duration of tissue exposure, to mention only two items. The sample obtained with a cascade impactor are such that it is essentially impossible to obtain data on the activity of individual particles. In addition, the cascade impactor has other disadvantages.

Suggested Equipment

THE IDEAL sampling method should simplify the task of obtaining the necessary information by collecting the sample in two fractions simulating the efficiency of the upper respiratory and alveolar retention. These fractions should readily permit tests for solubility, total activity, energy and decay rate as well as having the "alveolar retention" particles dispersed sufficiently for individual measurement of particle activity and other study. This suggests the use of two stages in series, the first of which should simulate the collecting efficiency of the upper respiratory tract. The second stage must collect the remainder of the airborne activity at least as well as the alveoli.

There are various possibilities for a first stage—a poor filter, a modified spiral,[2] a single stage impactor, an Aerotec cyclone tube[3] or the pre-impinger of May and Druett.[4] Among devices with adequate efficiencies for the second stage are the impinger, electrostatic precipitator or molecular filter. The choice made for the two stages in the case of a production operation handling a single material could well be different from that choice for sampling in a research laboratory or for weapons test monitoring.

The pre-impinger and impinger combination conveniently provides the two sample fractions ready for filtration. This first step in sample treatment would enable the immediate determination of solubility. The insoluble material is left dispersed on the filter ready for all subsequent tests. Two different physiological solutions could be used to simulate the solubility conditions encountered by the particles in the body. The non-uniformity factor for lung exposure is based on data obtained by radio-autographing the insoluble alveolar fraction. The number of particles is obtained by direct count of the spots on the film and the activity per particle distribution is derived from the spot sizes. As for any valid sample, the air samples obtained should be representative of the air breathed and typical of the period of exposure. While no sample can be perfect due to individual variations in breathing habits and exposure conditions, any bias in sampling and in evaluation should be avoided or corrected.

There presently exist several methods, using combinations as above noted, by which we are now able to sample properly for airborne radioactivity and approach a meaningful interpretation of the hazards present. Hence, there is no justification for further failure to sample properly. In particular, only by proper sampling can adequate data be obtained with which to determine the answer to the "particle problem."

Appendix

DIFFERENCES in respiratory retention and consequent dosage rates may be readily shown by an example. Three dusts were considered having the same median size but different standard deviations in their size distribution. The results are summarized in Table I, in which are seen the variations of retention following exposure.

Using the same three dusts, assuming an hour's inhalation exposure and further assuming that 1% of the particles have a specific activity of 20 curies/gram, four different concentrations of the three dusts are considered as they affect three different lung tissue systems. The resultant dose rates are seen in Table II.

References

1. ROBERTSON, O. H.: Phagocytosis of Foreign Material in the Lung. *Physiol. Reviews*, 21:115, 1941.

2. YAFFE, C. D., HOSEY, A. D., and CHAMBERS, J. T.: The Spiral Sampler—A New Tool for Studying Particulate Matter. *AMA Arch. of Indust. Hyg. & Occup. Med.*, 5:62, 1952.

3. HARRIS, W. B., and EISENBUD, M.: Dust Sampler Which Stimulates Upper and Lower Lung Deposition. *AMA Arch. of Indust. Hyg. & Occup. Med.*, 8:446, 1953.

4. MAY, K. R., and DRUETT, H. A.: The Pre-Impinger. *Brit. J. Indust. Med.*, 10:142, 1953.

AMERICAN INDUSTRIAL HYGIENE ASSOCIATION
14125 Prevost
Detroit 27, Michigan

Please send the following number of copies of Hygienic Guides at $.25 each:

_____Acetaldehyde	_____Cadmium	_____Hydrogen Sulfide
_____Amyl Acetate	_____Carbon Tetrachloride	_____Mercury
_____Aniline	_____Ethyl Alcohol	_____Sulfur Dioxide
_____Benzol	_____Formaldehyde	_____Trichloroethylene
_____Butyl Alcohol	_____Hydrogen Fluoride	_____1,1,1,—Trichloroethane

Please send _____ loose leaf binder(s) for the Hygienic Guides at $1.25 each.

Name _____

Address _____

Street and No. _____

City _____ Zone _____ State _____

Remittance must accompany orders for less than $2.00. Discount of 20% on orders of five or more Guides; 40% discount on orders of 100 or more Guides.

Radon Daughters in Mine Atmospheres

—A FIELD METHOD FOR DETERMINING CONCENTRATIONS

HOWARD L. KUSNETZ, M.S.
Occupational Health Field Station, Public Health Service
Salt Lake City, Utah

THE PHENOMENAL growth of the uranium mining industry in recent years has resulted in the exposure of large numbers of persons to high atmospheric concentrations of radon and its immediate degradation products. Uranium is also found associated with ores from many types of mines and may exist in sufficient quantity to make the hazard from radon and its daughters a real one. These circumstances necessitate the development of a method for the rapid determination of these radioactive daughters in the field in order to evaluate any hazards that might exist and to facilitate the control of such hazards. A rapid, on-the-spot, determination is also essential to check the efficacy of ventilation or other control methods by measuring "before" and "after" concentrations.

Two methods are currently used to measure radioactive contamination in mine air. The measurement of either radon alone or of the daughters alone may be made. It has been shown,[1,2] however, that given a mixture of radon and its daughters, the greater hazard by far is from the daughters. Therefore, use of the radon concentration as the only index of the hazard to an individual is poor practice. The daughter product concentration is much more significant and must itself be determined. It is conceivable that unusual equilibrium conditions may exist where the radon is virtually free of its daughters and would constitute the primary hazard. This is the rare case, however, and in almost all instances the daughters are the important hazardous contaminant.

The field determination of radon concentrations is at best cumbersome. The simplest equipment used by personnel of this station for radon collection and measurement includes a vacuum pump, scintillation cells, a photomultiplier tube and amplifier, a scaler, and a source of 110-volt 60-cycle A. C. power. Equipment for measuring daughter products, contrarily, comprises only a filter holder, a small hand-cranked pump, and a calibrated alpha survey meter, for example a Juno.*

Previous methods of measurement[3] utilize a technique of sampling for the daughters with a molecular membrane filter for a predetermined period of time, determining the activity on the filter and then relating this to atmospheric concentrations following, essentially, the method developed by Harley.[4] For any sampling time other than the predetermined period, an involved calculation has to be carried out by the field inspector. This technique assumes equilibrium conditions between the daughters. Where such conditions do exist, it is relatively simple to determine the concentration of the daughters in terms of micromicrocuries ($\mu\mu c$) per liter. Where non-equilibrium conditions exist, however, an error is introduced in calculating back to the original concentration in $\mu\mu c$/liter. The method presented here decreases the magnitude of that error.

One may consider the atmospheric concentration of radon daughters in terms of activity, expressed in micromicrocuries or disintegrations per minute (dpm) per unit volume. On the other hand, the level may also be considered in terms of the total alpha energy resulting from the ultimate decay of the daughter products in the body. There will be essentially no selective inhalation or selective retention of the radon daughters by the lungs as these elements will be carried on atmospheric dust, inhala-

*Available from Technical Associates, Burbank, California, or Espy Manufacturing Company, New York, New York.

tion and retention being characteristic of the properties of the dust. Due to the short half-lives of the first four radon daughters, they will all decay to RaD in the lungs. Therefore, the total internal alpha-energy dose to the lung tissue bears a direct relationship to the total alpha energy which would result from the complete decay of a given concentration of radon daughters in air. It then becomes possible to express atmospheric concentrations in terms of the total alpha-energy dose without being immediately concerned with the specific amounts of the several isotopic species. This results in a considerable simplification of terminology and calculation.

If we accept as the tolerance level in the working atmosphere for an eight-hour day 100 $\mu\mu$c/liter each of RaA, RaB, and RaC, we can then determine the total alpha energy in Mev which would result from the complete decay of this concentration by the following method.

Each atom of the radon daughters, when it decays through RaC′, will produce a given amount of alpha energy. It is this alpha energy, released internally, which causes damage to the lung tissues. RaA is itself an alpha emitter with an energy of 6.0 Mev per alpha particle. In decaying through RaC′, the RaA then contributes another 7.7 Mev per atom (the alpha decay energy of RaC′). In a like manner, RaB and RaC will each eventually contribute 7.7 Mev of alpha energy per atom. Because of the extremely short half life of RaC′ (2.73×10^{-6} minutes), the internal hazard present from the atmospheric RaC′ can be neglected. The total alpha energy from 100 $\mu\mu$c/liter of each of the first three radon daughters is then:

$$\text{for RaA: } \frac{100\ \mu\mu c}{\text{liter}} \times \frac{2.22\ \text{dpm}}{\mu\mu c} \times \frac{1}{.227^*} \times \frac{13.7\ \text{Mev}}{\text{atom}} = 13400\ \text{Mev/liter}$$

$$\text{for RaB: } \frac{100\ \mu\mu c}{\text{liter}} \times \frac{2.22\ \text{dpm}}{\mu\mu c} \times \frac{1}{.0259^*} \times \frac{7.7\ \text{Mev}}{\text{atom}} = 66000\ \text{Mev/liter}$$

$$\text{for RaC: } \frac{100\ \mu\mu c}{\text{liter}} \times \frac{2.22\ \text{dpm}}{\mu\mu c} \times \frac{1}{.0352^*} \times \frac{7.7\ \text{Mev}}{\text{atom}} = 48560\ \text{Mev/liter}$$

$$\text{Total} = 127960\ \text{Mev/liter}$$

For practical calculations this can be considered as 1.3×10^5 Mev/liter. Complete decay of 100 $\mu\mu$c/liter of RaC′ would yield: $100 \times \frac{2.22}{2.54 \times 10^5} \times 7.7 = 6.8 \times 10^{-3}$ Mev/liter. This is negligible compared to the values for RaA, RaB, and RaC.

Since the reading on the field instrument will be interpreted in terms of dpm, we must equate the activity on the filter at a given time after the end of sampling with the original atmospheric concentration. For convenience, throughout the remainder of this discussion, we shall assume that the count is made exactly 60 minutes after the end of sampling (T_{60}). We assume further that an "instantaneous" sample was taken. This eliminates the need for calculating, at present, the build-up and decay of the daughters on the paper during the sampling period.

It can be shown, by solving an equation of the Bateman type, that there will be 0.091 alpha disintegrations per minute expressed as RaC′ at T_{60} from an initial amount of RaA by itself equivalent to 1 $\mu\mu$c at T_0. From RaB, similarly, there will be 0.764 alpha disintegrations per minute at T_{60} from 1 $\mu\mu$c at T_0. For 1 $\mu\mu$c of RaC, the T_{60} figure is 0.271. From an initial amount of 100 $\mu\mu$c/liter of each of the daughters, there will be 112.6 dpm of alpha activity on the filter after 60 minutes. (This alpha activity, of course, is due to the decay of RaC′). Given an equilibrium condition at the tolerance level, a meter reading showing 113 dpm 60 minutes after the end of sampling indicates a potential total alpha energy of 1.3×10^5 Mev/liter.

This relationship suggests using the alpha survey meter reading as an index describing the potential total alpha energy of the concentration of daughter products present in the atmosphere. A reading indicating five hundred seventy dpm, for example, would then show that a condition of five times the tolerance level, or a total alpha-energy release of 6.5×10^5 Mev/liter existed. If we were to calculate the total alpha energy available from 500 $\mu\mu$c of each of the daughters, we would find the result to be identical.

*This represents λ, or the number of disintegrations per unit time—one minute in this case.

The foregoing example was confined to equilibrium conditions. Actually, in a mine, this condition would exist only in a large room with no ventilation. Of 45 unventilated mines sampled, the mean equilibrium condition was 1 : 0.88 : 0.79. (The RaB and RaC were present in amounts equal to 88% and 79% of their equilibrium values, respectively.) In 45 mines with ventilation, the corresponding mean ratio was 1 : 0.46 : 0.34. The most extreme non-equilibrium condition recorded had a ratio of 1 : 0.15 : 0.06.[5] By utilizing the exact factor (112.6 in the example), an error is introduced into the estimate of the percent of the tolerance level existing in the mine. Underestimating the error would lead to a false sense of security and would permit a dangerous situation to go uncorrected. A small overestimation of the hazard would be acceptable, since this would act as a safety factor. A gross overestimate, however, would result in the expenditure of much effort to correct a non-existent condition.

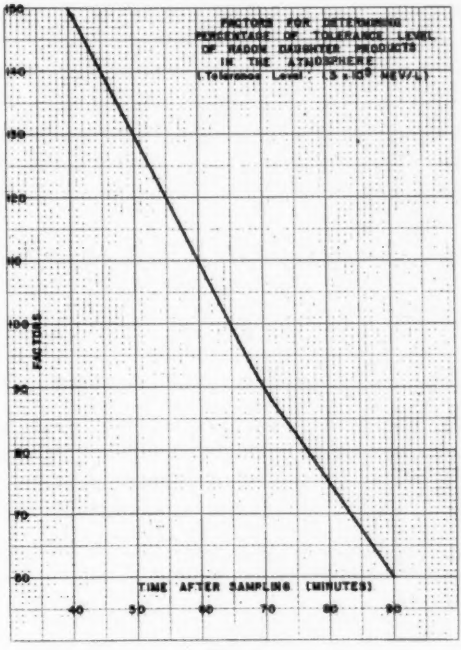


Fig. 1.
Factors for determining percentage of tolerance level of radon daughter products in the atmosphere.

PERCENT ERROR OF TOLERANCE LEVEL ESTIMATION WITH ADJUSTED FACTORS FOR DIFFERENT TIMES AND EQUILIBRIUM RATIOS

Equilibrium Ratio	Time After Sampling	Factor	Percent Error
1 : 1 : 1	40	150	7
	50	130	3
	60	110	3
	70	90	3
	80	75	7
	90	60	2
1 : 0.9 : 0.8	40	150	8
	50	130	4
	60	110	3
	70	90	12
	80	75	10
	90	60	4
1 : 0.45 : 0.35	40	150	2
	50	130	2
	60	110	2
	70	90	4
	80	75	11
	90	60	6
1 : 0.15 : 0.06	40	150	7*
	50	130	7*
	60	110	2*
	70	90	3
	80	75	12
	90	60	7

*Percent underestimated.

Another complicating factor in the use of just one figure for calculating atmospheric concentrations is the difficulty in making a reading at exactly one given time. If the 60-minute factor were used, readings made after 60 minutes would tend to underestimate the level and readings made sooner would overestimate it. Therefore, a series of factors for different time intervals between collection and reading has been determined. These factors also have been adjusted to reduce the error in underestimating the exposure. The factor-time relationship is shown in Fig. 1. Ranges of error due to use of these factors are shown in the table above.

These factors were determined on the basis of an instantaneous sample which did not consider build-up and decay of the daughters on the filter during sampling. Since no instantaneous samples (less than 10 seconds) are taken under practical conditions, an attempt was made to determine the relative accuracy of the factors when applied to five and ten minute sampling times.

A given atmospheric concentration of daughters was assumed. Using the equations developed by Tsivoglou and Ayer[6] the number of atoms of each daughter remaining on the filter paper at the end of sam-

pling was determined. The number of alpha dpm at various times after the end of sampling was calculated. When the factor was applied to these activity readings, a multiple of the tolerance level was determined. For both equilibrium and non-equilibrium concentrations, the maximum error was 12% on the safe side.

Calibration of Instruments

THE ALPHA survey meter used must be calibrated in terms of dpm of RaC'. This may be accomplished by using a RaC' source and cross-checking the survey meter against a laboratory proportional counter. The RaC' source is prepared by the following procedure. Some high-grade uranium ore or a freely emanating radium solution is kept in a closed container to permit the build-up of radon and its daughter products. This radon daughter concentration is sampled through a filter such as Whatman 41 or Millipore.® This is then permitted to stand for 15-20 minutes to assure virtually complete decay of the RaA. The only alpha emitter remaining on the paper then is RaC'.

Field Operating Method

1. On a suitable filter, collect a sample of 100-250 liters within a five to ten minute period.

2. Take an alpha survey meter reading of the filter activity from 40 to 90 minutes after end of sampling; convert this to dpm.

3. Divide this reading by the number of liters sampled to give dpm/liter.

4. Divide the dpm/liter by the factor on the graph.

5. The resultant figure gives the multiple or fraction of the tolerance level (1.3 x 10^5 Mev/liter) existing in the air.

Summary

A NEW CONCEPT of describing the tolerance level of radon daughters has been presented. This concept is in terms of the alpha-energy dose resulting from the complete decay of the daughters. A rapid field method for determining atmospheric concentrations of radon daughters in terms of Mev of alpha energy/liter has been shown. No attempt has been made to set a maximum allowable concentration for radon and/or its daughters. Should an MAC different from the tolerance level given in this paper be adopted, the factors in Fig. 1 would change by an appropriate constant. The method itself would remain the same.

Bibliography

1. MORGAN, K. Z.: *Maximum Permissible Concentration of Radon in the Air.* Quoted by Tsivoglou, et al, in "Occurrence of Non-Equilibrium Mixtures of Radon and Its Daughters," *Nucleonics*, 11:40, (September) 1953.

2. SHAPIRO, J.: *An Evaluation of the Pulmonary Radiation Hazard from Radon and Its Daughter Products.* Doctoral Thesis, University of Rochester, Rochester, N.Y., 1954. (Published as Report UR-298.)

3. An Interim Report of a Health Study of the Uranium Mines and Mills, U.S.P.H.S. and Colorado State Department of Public Health, 1952.

4. HARLEY, J. H.: Sampling and Measurement of Airborne Daughter Products of Radon. *Nucleonics*, 11:12, (July) 1953.

5. AYER, H. E.: *Control of Radon and Its Daughters in Mines by Ventilation*, AECU-2858. Technical Information Service, Oak Ridge, Tennessee, (March) 1954.

6. TSIVOGLOU, E. C.: et al, Cited in reference 1.

The Most Experienced
FILM BADGE SERVICE
for
PERSONNEL MONITORING
ENVIRONMENT
EMERGENCY CONTROL
ST. JOHN X-RAY LABORATORY
Califon, New Jersey
Established 1925

Phone CApitol 7-5708
211 MILBY STREET
HOUSTON 3, TEXAS
OCCUPATIONAL HEALTH LABORATORIES
Dithizone method for lead. Urinary coproporphyrin
Phone CApitol 7-5708

Radioactive Waste Disposal for the Small Isotope User

HERMAN CEMBER, Assistant Professor
Graduate School of Public Health, University of Pittsburgh

THE PROBLEM of radioactive waste disposal is a continually recurring one, and one for which a limited number of specific recommendations exist.[1,2] In view of the many parameters that must be considered in the establishment of specification-type recommendations, overall policy only is usually set forth, and recommendations are frequently made only in the general terms of performance-type specifications. This type of recommendation leaves much to the discretion of the individual radioisotope user, and enables him to make decisions designed to meet his particular need.

It has been my experience that many people concerned with environmental safety frequently raise questions regarding the interpretation of the performance-type recommendations for waste disposal. In making suggestions, I try whenever possible to utilize existing facilities rather than to resort to special techniques.

A convenient way for the small isotope user to dispose of much of his radioactive waste is by conversion of the isotope to a form that would permit it to be dissolved in water and discharged by way of the sewer. This may be safely done if certain precautions to prevent exposure hazard due to ingestion of contaminated water are followed. One such precaution is isotopic adulteration. When this device is resorted to, then the degree of adulteration must be such that continuous ingestion of the adulterated mixture irradiates the critical organ at a dose rate not exceeding 300 mr per week. This adulteration, using Fe^{59} as an example, may be calculated as follows:

$$\text{maximum permissible body load} = 11 \text{ microcuries}$$

$$\text{total mass of iron in the body} = 3 \text{ grams}$$

$$\therefore \text{ specific activity of adulterated iron} = \frac{11}{3} = 3.67 \frac{\mu c}{\text{grams}} \qquad (1)$$

An isotopic mixture of iron containing Fe^{59} in this ratio, even if continually ingested, may not produce overexposure. This simple calculation considers the isotope to be uniformly distributed throughout the body. Since this assumption is not true for most elements, the above calculation is only an approximation. A more exact calculation for the adulteration of the radioisotope considers the critical organ and the fraction of the total body load present in the critical organ. The critical organ is usually that organ that has the greatest concentration of the radioisotope deposited in it. However, since a number of factors, including radiosensitivity of the tissue, the physiological relation of the organ to the body as a whole, and the biological half life, must be considered in the determination of the critical organ, concentration of the radioisotope is not the sole criterion. The critical organ may be defined as the organ suffering radiation damage that results in the greatest insult to the body. Considering these factors, the maximum safe specific activity may be calculated as follows:

$$\frac{\text{microcuries}}{\text{gram}} = \frac{L \times f}{M \times C} \qquad (2)$$

L = maximum permissible body load, microcuries*
f = fraction of total body present in the critical organ*
M = mass of critical organ, grams*
C = concentration of the element in the critical organ, grams per gram*

*Numerical values for these variables may be found in Handbook 52.

In the case of Fe^{59},

L = 11 microcuries
M = 5000 grams (blood is the critical organ)
f = 0.64
C = 5×10^{-4} grams iron per gram blood

$\therefore$ maximum specific activity =

$$\frac{11\ \mu c \times 0.64}{5 \times 10^3 \text{ grams} \times 5 \times 10^{-4} \frac{\text{grams}}{\text{gram}}}$$

$$= 2.82 \frac{\mu c}{\text{gram}}$$

According to this calculation, Fe^{59}, whose specific activity is 2.82 microcuries per gram, may be disposed of by any means. Should this iron be accidentally ingested, then the radiation dose rate to the blood, from the iron 59 absorbed by the blood, can never exceed 300 mr per week. However, it should be emphasized that these calculations consider only the internal radiation hazard. Obviously, a concentration of Fe^{59}, regardless of its specific activity, may constitute an external radiation hazard. For example, if 100 grams of iron containing 282 microcuries Fe^{59} approximates a point source, then the dose rate at a distance of 20 centimeters from the source is 7.5 mr per hour. Disposal by way of the sewer and subsequent dilution therein virtually eliminates the possibility of creating an external radiation hazard in this manner.

For some of the isotopes that may be encountered, the maximum specific activities calculated according to equation (2) are:

Radioisotope	Maximum Specific Activity
S^{35}	1.1 μc/gram
Fe^{55}	256 μc/gram
Fe^{59}	2.8 μc/gram
Cr^{51}	2900 μc/gram
Co^{60}	6000 μc/gram
Ag^{110}	2700 μc/gram

The high values for Ag^{110}, Co^{60}, and Cr^{51} should be noted. These high values arise from the fact that these elements are present in the body in trace quantities (less than .03 grams),[3] and are only slightly absorbed from the gastro-intestinal tract. Calculations based on absorption into the critical organ will therefore show high specific activities. One possible explanation for the high activities is that the critical organ listed in Handbook 52 is not correct. Recognizing this fact, the International Sub-Committee on Permissible Dose for Internal Radiation has recalculated the maximum permissible concentrations for the different isotopes using the gastro-intestinal tract as an alternate critical organ. These new data, which are soon to be published, take into account the transient dose from radioisotopes merely passing through the body. If the inside of the gastro-intestinal tract, a long tube coaxial with the body and open at both ends, is considered to be outside the body, then the dose to the gastro-intestinal tract due to radioisotopes passing through may be thought of as an external dose delivered internally. Since other factors will prevent the ingestion of significant quantities of any of these elements, the hazard due to radiation from concentrated transient quantities of properly adulterated ingested radioisotopes is minimized. However, a real external radiation hazard, as described above, may result from the disposal of large quantities of the radioisotope via the sewerage system. To minimize this possibility, the adulterated radioisotope is diluted before discharge into the sewer to a concentration 10 times that recommended in Handbook 52 for continuous ingestion. This diluted waste may then be flushed down with running water. If the liquid waste is slowly discharged into the drain by way of a constant drip bottle as described in Handbook 49, then additional dilution and mixing in the waste lines will be achieved. This will further decrease the probability of external radiation hazards due to an unmixed radioactive liquid slug or to a buildup of the radioisotope in the sewerage system.

If radioisotopes are disposed of in the manner described, then no more than one sink in a laboratory should be used for this purpose. Furthermore, a routine monitoring program must be established in order to make certain that no build-up of radioactivity occurs in the waste lines inside the building. It should be emphasized that all the calculations described here consider only the health hazard, and do not consider the effects of sub-tolerance radiation or contamination level on tracer experiments. It should also be understood that the use of the criteria described herein are applicable to the case where radioisotopes are used in tracer or at most in low millicurie quantities, and where disposal from any labora-

tory occurs infrequently or intermittently.

The fact that several laboratories in the same building may simultaneously discharge liquid wastes into the sewerage system is implicit in the fact that the maximum permissible concentrations listed in Handbook 52 are calculated on the basis of continuous ingestion of the radioisotope for the lifetime of the individual. In a single accidental intake of the isotope, the concentration of the radioisotope may greatly exceed the concentration permitted for continuous ingestion. In the case of Cr^{51}, for example, the MPC for continuous ingestion given in Handbook 52 is 0.5 microcuries per milliliter; if the contaminated water is ingested for only one day, then the MPC is 14.7 microcuries per milliliter. The same argument is used to justify simultaneous discharge of different radioisotopes into the sewerage system. The crux of this argument is the fact that disposal into the sewerage system from any one laboratory is intermittent, and that the probability of drinking the contaminated water before further dilution by other wastes in the system is almost zero. Since ingestion as the result of an accident in the sewerage system would probably be limited to a contaminated water intake not exceeding the average daily intake of about two liters, and since the permitted single intake concentration is much greater than that recommended for continuous ingestion, the discharge of adulterated radioactive liquid wastes into the sewerage system at the present levels of radioisotope consumption by non AEC users seems justified.

Bibliography

1. Recommendations for Waste Disposal of Phosphorous 32 and Iodine 131 for Medical Users. National Bureau of Standards Handbook #49, Government Printing Office, Washington, D. C.

2. Recommendations for the Disposal of Carbon 14 Wastes. National Bureau of Standards Handbook #53, Government Printing Office, Washington, D. C.

3. Recommendations of the International Commission on Radiological Protection and of the International Commission on Radiological Units. National Bureau of Standards Handbook #47, Washington, D. C.

The Philadelphia Meeting

THE Seventeenth Annual Meeting of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION will be held in Philadelphia, April 23-27, 1956. As in the past, AIHA is meeting with the Industrial Medical Association, the American Association of Industrial Nurses, the American Association of Industrial Dentists, and the American Conference of Governmental Industrial Hygienists. These groups make up the Industrial Health Conference. All scientific sessions are to be held in Convention Hall. The AIHA program lists 77 papers in the various sessions. Field trips are scheduled for Tuesday morning, April 24. The annual business meeting will be held Wednesday afternoon, April 25. Highlight of the AIHA meeting will be the presentation of the Donald E. Cummings Memorial Lecture on Wednesday evening at the annual banquet.

✦ President's Page

THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION was formed in 1939 with only a few members, but with sound objectives and good leadership. In the short span of fifteen years, the ASSOCIATION has grown to a membership of approximately 1000 and has assumed a place of leadership in scientific and professional affairs of industrial hygiene. This has been accomplished by volunteer effort on the part of a lot of people; committees, officers and the Board. The burden of work required by the Executive Secretary's office reached the point where this could not be handled on a volunteer basis and a part-time Executive Secretary was employed during 1955.

The employment of a part-time Executive Secretary was coincident with several other important events in the affairs of the ASSOCIATION. These include work of the Fellowship Committee and the great expansion of the technical committees with pending publications. All of these things have changed a number of the administrative problems of the ASSOCIATION, as well as incurring responsibilities which the ASSOCIATION has not had in the past.

For reasons of potential responsibilities connected with the whole operation of the ASSOCIATION, your Board of Directors has sought legal counsel for advice. On the overall structure of AIHA, in terms of the ASSOCIATION'S various programs and potential responsibilities, we are advised that the ASSOCIATION should incorporate. Incorporation would accomplish the following:

1. Permit AIHA to legally receive and handle funds which might come as a result of the Fellowship Program.
2. Protect members of AIHA against legal liability in the event of litigation.
3. Provide a better overall structure for the ASSOCIATION which would more effectively enable it to carry out its various functions.

In order to acquaint you more fully with these details, a letter will be sent to every member of AIHA in the near future. The matter of incorporation will be presented to the membership for voting at our annual business meeting at the time of the Philadelphia Conference.

Your Officers and Board of Directors have given the whole matter of incorporation very serious thought and beyond this have sought competent legal counsel on the matter. Incorporation will be a most important step in the future of the ASSOCIATION. Please give it your careful consideration. —N. V. HENDRICKS

HYGIENIC GUIDE SERIES

1,1,1,—TRICHLOROETHANE (METHYL CHLOROFORM)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 500 parts of vapor per million parts of air, by volume (ppm).[2] This material has not been widely used in industry for a sufficient period to indicate the correctness of the above maximum allowable concentration.

(1) *Basis for Recommendation*: Toxicologic observations on animals.[1]

B. SEVERITY OF HAZARDS:

(1) *Health*: Moderate. Volatility is high. Readily absorbed through the lungs. In acute exposures of animals, the most important toxic action is a functional depression of central nervous system leading ultimately to respiratory or cardiac failure. Experiments in dogs have indicated that this material can induce ventricular arrhythmia, similar to other chlorinated solvents.[6] Experiments from one laboratory indicated that rats will tolerate higher levels on acute exposure than with trichloroethylene. On chronic exposures some changes in liver histology were noted but not the severe effects seen with carbon tetrachloride. The guinea pigs seemed to respond more or less similarly to trichloroethylene exposures. Growth depression occurred at 650 ppm. Chronic exposures showed moderate fatty degeneration of the liver but no liver necrosis or kidney injury.[1] As in most solvents, dermatitis may result from repeated skin contact. There is no evidence of absorption through the skin.

(2) *Fire*: None. The decomposition products, however, may be quite toxic.

C. SHORT EXPOSURE TOLERANCE: Uncertain except that animals died after three hours exposure to 18,000 ppm, and after seven hours exposure at 14,500 ppm. However, 5,000 ppm caused definite but mild narcotic effects after exposure for one hour.[1,8] Persons breathing 1900 parts per million experienced definite anesthesia effects within five minutes.[8]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Uncertain except that animals were anesthetized after five minutes exposure to 18,000 ppm.[1]

II. Significant Properties

A volatile, colorless liquid.

Chemical formula:	CH_3CCl_3
Molecular weight:	133.42
Specific gravity:	1.346 (15°C/4°C)
Boiling point:	74.1°C
Relative vapor density:	4.65 (air=1)
1 ppm of vapor (25°C and 760 mm Hg):	0.00546 mg/l
1 mg/l (25°C and 760 mm Hg):	182 ppm
Vapor pressure:	132 mm of Hg at 25°C (calculated)
Odor:	Similar to chloroform; faintly detectable at 100 ppm[8]
Solubility:	Insoluble in water, but miscible with alcohol, ether, and most organic solvents.

III. Industrial Hygiene Practice

A. RECOGNITION:

(1) By its chloroform-like odor.

(2) Used as a degreasing and cleaning agent. In many instances has been substituted for the more toxic carbon tetrachloride.

B. EVALUATION OF EXPOSURE:

(1) *Instrumentation*: The Halide Meter (Davis Emergency Equipment Co., Newark, N. J.), the mass spectrometer, and gas interferometer may be used.

(2) *Chemical*: Collection in chloride-free alcohol in an all-glass device or on silica gel, followed by subsequent hydrolysis and determination of chloride,[3,4,5] or colorimetrically.[7] None of these methods is specific for 1,1,1-trichloroethane.

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheres below 500 ppm. General ventilation may be sufficient for brief exposures or those resulting from very small quantities of the solvent. With prolonged exposures or with elevated temperature operations, process ventilation will be required. Good personal hygiene should be practiced by exposed personnel. Skin contact should be avoided, or prevented by the use of protective clothing.

IV. Specific Procedures

Since no accidents involving humans have been reported, the following suggestions are made solely on the knowledge of toxicity in experimental animals:

A. FIRST AID: Removal from exposure is of first importance. The person should be put to bed and a physician called at once. Contaminated clothing should be removed and the skin cleansed with soap and water. If central nervous system is greatly depressed, artificial respiration may be needed and oxygen therapy may be indicated.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES: The cardiac rhythm should be watched carefully in any case of anaesthesia produced by the substance. Adrenalin should not be given to these patients. As with other chlorinated hydrocarbon exposures, these patients should be watched carefully for signs of pulmonary irritation and renal or liver damage.

V. Literature References

1. ADAMS, E. M., et al: *Arch. of Ind. Hyg. and Occup. Med.*, 1:225, 1950.
2. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health*, 11:522, 1955.
3. CRALLEY, L. V., et al: *J. Ind. Hyg. & Tox.*, 25:172, 1943.
4. ELKINS, H. B.: Chemistry of Industrial Toxicology. John Wiley and Sons, Inc., New York, New York, 1950.
5. JACOBS, M. B.: The Analytical Chemistry of Industrial Poisons, Hazards and Solvents, 2nd Edition. Interscience Publishers, Inc., New York, 1949.
6. RENNICK, B. R., et al: Federation Proceedings, 8:327, 1949.
7. ROGERS, G. W., and KAY, K. K.: *J. Ind. Hyg. & Tox.*, 29:229, 1947.
8. ROWE, V. K. (Dow Chemical Co., Midland, Mich.): Personal communication.
9. VON OETTINGEN, W. F.: The Halogenated Hydrocarbons; Toxicity and Potential Dangers. Public Health Service Publication No. 414, U. S. Government Printing Office, Washington, 1955.

ETHYL ALCOHOL (ETHANOL)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 1,000 parts of vapor per million parts of air, by volume (ppm).[1]

(1) *Basis for Recommendation*: Animal experimentation and observations of humans.

B. SEVERITY OF HAZARDS:

(1) *Health*: Low. This is one of the least hazardous industrial organic solvents. It is practically devoid of inhalation hazard.[5] Ethyl Alcohol acts principally as a narcotic.[4]

(2) *Fire*: Moderate. Explosive limits are 3.28% and 18.95% by volume. Flash point is 14°C. (57°F).

C. SHORT EXPOSURE TOLERANCE: 8,000 ppm probably endurable without symptoms. Some eye and nasal irritation above 5500 ppm.[5]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown.

II. Significant Properties*

Ethyl Alcohol is a flammable, colorless liquid, with a vinous odor.

Chemical formula:	C_2H_5OH
Molecular weight:	46.07
Specific gravity:	0.789 (20°C/4°C)
Boiling point:	78.5°C
Relative density:	1.59 (air=1)
Vapor pressure:	11 mm at 20°C

*The indicated properties are those of absolute ethyl alcohol. The commercial product may be either 95% pure or a denatured grade of a specific type formula.

1 ppm of vapor (25°C and 760 mm Hg):	0.001881 mg/l
1 mg/l (25°C and 760 mm Hg):	532 ppm
Solubility:	In water, ethyl ether, and in methyl alcohol.

III. Industrial Hygiene Practice

A. RECOGNITION:

(1) By its vinous odor.

(2) Major uses are in beverages, perfumes, flavoring extracts, pharmaceuticals, cosmetics, cleaning solutions, lacquers, fuel, and manufacturing of plastics, photographic film, rayon, smokeless powder, and esters.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Direct determination by the Davis Vapotester Model M-6 (Davis Emergency Equipment Co., Newark, New Jersey), the mass spectrometer, or the interferometer.

(2) *Chemical Method*: Collection in water in an all-glass device, with subsequent determination by dichromate oxidation,[3,7] or with iodine pentoxide.[2]

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheric concentrations below 1000 ppm. Under most circumstances, good general ventilation will accomplish this. In enclosed spaces or with elevated temperature processes, local process ventilation will be required.

IV. Specific Procedures

A. FIRST AID: Usual procedures, such as removal from exposure, washing of affected skin areas, and irrigation of the eyes with water, should be practiced.

B. BIOCHEMICAL ASSAY: Determination in the blood and urine may be made by means of the iodine pentoxide method.[2] Various commercial direct reading instruments are also available for determining alcoholic blood levels from the exhaled breath content.

C. SPECIAL MEDICAL PROCEDURES (including preplacement): None are usually necessary. Individuals who are being treated with tetraethyl thiuram disulfide (Antabuse) should not be assigned to ethyl alcohol exposures.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health*, 11:522, 1955.

2. HAGGARD, H. W., and GREENBERG, L. A.: *J. Pharmacol.*, 52:137, 1934.

3. JACOBS, M. B.: The Analytical Chemistry of Industrial Poisons, Hazards and Solvents, Vol. I, 2nd Edition. Interscience Publishers, Inc., New York, 1949.

4. LEHMAN, K. B., and FLURY, F.: Toxicology and Hygiene of Industrial Solvents. The Williams and Wilkins Co., Baltimore, 1943.

5. LESTER, D., and GREENBERG, L. A.: *Quart. J. of Studies on Alcohol*, 12:167, 1951.

6. VON OETTINGEN, W. F.: The Aliphatic Alcohols: Their Toxicity and Potential Dangers in Relation to Their Chemical Constitution and Their Fate in Metabolism, Public Health Bulletin No. 281. U. S. Government Printing Office, Washington, D. C., 1943.

7. WILLIAMS, M. B., and REESE, H. D.: *Anal. Chem.*, 22:1556, 1950.

TRICHLOROETHYLENE

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 200 parts of vapor per million parts of air, by volume (ppm).[3] This level is currently believed to represent a maximum that should not be exceeded for repeated daily exposure; it is not to be used as an integrated average concentration.

(An average concentration of 100 ppm is believed, in the United States, to be without any probable risk). Neurologic changes have been reported from prolonged exposure.[6]

(1) *Basis for Recommendation*: Human and animal experiences.[1,8]

B. SEVERITY OF HAZARDS:

(1) *Health*: Moderate. Exposures to 1000-3000 ppm may produce dizziness, nausea, eye and respiratory irritation, and possibly injury to the liver and central nervous system. Higher concentrations may result in unconsciousness and death. Dermatitis may result from repeated contact with the liquid or with high concentrations of vapors.

(2) *Fire*: Non-inflammable. Decomposition products found in the presence of open flames or hot metals may be quite toxic.

C. SHORT EXPOSURE TOLERANCE: 3000 ppm or above for short exposures may produce varying degrees of "drunkenness," or unconsciousness. These effects may be greatly enhanced by alcoholic intake before, during, or after exposure. Carbon monoxide has been reported to produce a synergistic effect. From 11,500 to 13,000 ppm for 30 minutes will produce deep unconsciousness in experimental animals;[7] any exposure at or above these concentrations may be fatal. Concentrations of vapor below these values can produce similar serious effects if liquid or vapor has been excessively heated (presence of flames) to produce toxic decomposition products.

D. ATMOSPHERIC CONCENTRATIONS IMMEDIATELY HAZARDOUS TO LIFE: 20,000 ppm is fatal to rabbits in two hours.[9]

II. Significant Properties

Trichloroethylene is a clear, colorless, non-inflammable liquid.

Chemical formula:	CCl_2CHCl
Molecular weight:	131.4
Specific gravity:	1.46 at 20°/4°C
Boiling point:	87°C
Vapor pressure:	57.8 mm Hg at 20°C
Odor:	Sweetish, resembling odor of chloroform
Solubility:	In alcohol, ether, and oils; slightly, in water.
1 ppm of vapor (25°C and 760 mm Hg):	0.00536 mg/liter
1 mg/l (25°C and 760 mm Hg):	186 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: Used most frequently as solvent degreaser, dry-cleaner, thinner for varnishes and solvent for rubber; a common compound of so-called "safety solvents" and rug and upholstery cleaners.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Automatic sampling and analysis by Davis Halide meter or other combustion-type meters, suitably calibrated.

(2) *Chemical Method*: Collection in either isopropyl alcohol or silica gel, with subsequent hydrolysis and determination of chloride content.[4] Not specific for trichloroethylene.

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheres below 200 ppm. This will usually require process ventilation, especially if elevated temperatures are used. Tanks should be kept covered whenever possible. Degreasing tanks should be heat-controlled with periodic inspection. Avoid unnecessary contact of skin with liquid or high concentration of vapors. Inert gas welding should not be done in presence of vapors. Avoid flames or overheating of liquid or vapors.

IV. Specific Procedures

A. FIRST AID: Remove patient immediately from exposure. If unconscious, administer therapeutic oxygen and call a physician.

B. BIOCHEMICAL ASSAY: Trichloroacetic acid in urine determined according to the Fujiwara-pyridine method[5] as modified by Ahlmark.[2] Values should not exceed 75 mg/l taken after repeated daily sampling, for three to five days after exposure. Urinalysis should not be used as sole criterion of exposure, because of questionable reliability as an index of trichloroethylene exposure.

C. SPECIAL MEDICAL PROCEDURES (including preplacement): Only individuals free of liver disease, kidney disease, and alcoholism should be employed. Over-exposed personnel should be hospitalized and treatments directed toward restoring normal renal function.

V. Literature References

1. ADAMS, E. M., et al: *Arch. of Ind. Hyg. & Occup. Med.*, 4:469, 1951.
2. AHLMARK, A., and FORSSMAN, S.: *Arch. of Ind. Hyg. & Occup. Med.*, 3:386, 1951.
3. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health*, 11:521, 1955.
4. ELKINS, H. B.: Chemistry of Industrial Toxicology. John B. Wiley and Sons, Inc., New York, 1950.
5. FUJIWARA, K.: *Abhandl. Naturforsch. Ges. Rostock*, 6:33, 1914.
6. GRANDJEAN, E., et al.: *Brit. J. Ind. Med.*, 12:131, 1955.
7. HENDERSON, Y., and HAGGARD, H.: Noxious Gases. Reinhold Publishing Corp., New York. 1943.
8. KLEINFELD, M., and TABERSHAW, I. R.: *N. Y. State Dept. of Labor Monthly Rev.*, 33:41, 1954.
9. MCCORD, C. P.: *JAMA*, 99:409, 1932.

MERCURY

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 0.1 milligrams per cubic meter of air.[1] (Calculated as *Mercury* in the case of compounds). This may be too high for volatile alkyl mercury compounds [e.g.: Hg $(C_2H_5)_2$].

(1) *Basis for Recommendation*: Absence of clinical evidence in humans exposed to 0.2 mg/cu m of vaporized or finely divided mercury,[2] and animal experimentation.[2]

B. SEVERITY OF HAZARDS:

(1) *Health*: Severe. Chronic exposure may result in cumulative poisoning, predominated by nervous and psychic symptoms. Acute intoxication by inhalation occurs less frequently, but may be accompanied by stomatitis, gingivitis, salivation and diarrhea.[8] Dermatitis has occurred from cutaneous contact with alkyl or aryl mercuric salts or mercury fulminate.[6]

(2) *Fire*: None.

C. SHORT EXPOSURE TOLERANCE: Exposure of rabbits for four hours to vapor concentrations of 28.8 mg/cu m induced severe damage to the kidneys, liver, brain, heart, lungs and colon.[2]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown.

II. Significant Properties

Mercury is a metal, liquid at ordinary temperatures.

Chemical formula:	Hg
Molecular weight:	200.61
Specific gravity:	13.534 at 25°C
Boiling point:	357.3°C
Melting point:	-38.9°C
Vapor pressure:	0.000775 mm at 10°C 0.00182 mm at 20°C 0.00407 mm at 30°C[7]
At 25° and 760 mm Hg:	
1 ppm of vapor:	0.0082 mg/l
1 mg/l:	121.5 ppm
Solubility:	Insoluble in water; soluble in inorganic acids.

III. Industrial Hygiene Practice

A. RECOGNITION: Potential hazards include the heating of amalgams, welding near induction furnaces, and the use and storage of organic mercurial compounds in the treatment of seed. A former severe hazard in the fur and felt hat industries has been virtually eliminated in most states by legislation prohibiting use of mercuric compounds, in these trades. Other hazardous uses may occur in laboratories; in the manufacture of mercury vapor lamps, neon tubes, thermometers, and barometers; in the electrochemical industry, through the use of mercury electrodes; in the use and manufacture of antifouling paints; and in munition plants from mercury fulminate.

B. EVALUATION OF EXPOSURE:

(1) *Physical Methods*: Properly calibrated commercial photoelectric exposure meters for the presence of mercury vapor in air, may be used. Photometric devices, using selenium sulfide papers, are also available.

(2) *Chemical Methods*: (a) Collect vapor or dusts by means of impinger, using potassium iodide-iodine solution, and determine colorimetrically by means of copper sulfate and sodium sulfite.[3] (b) Colorimetric determination with di-β-naphthylthiocarbazone, following trapping of the mercury in acidified 1% potassium permanganate.[4]

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheric concentration below 0.1 mg/cu m by using enclosure and/or ventilation. Reduce spillage of element on floors and bench top cracks to a minimum and if it occurs, clean up promptly. The use of calcium polysulfide solution on floors and walls is beneficial.[9] Frequently inspect all mercury boilers and stills for leaks. Iodized charcoal respirators may be used for short exposures.[10]

IV. Specific Procedures

A. FIRST AID: None.

B. BIOCHEMICAL ASSAY: Urinary determinations of mercury should be made at six

month intervals. A suggested method is that of Elkins.[5]

C. SPECIAL MEDICAL PROCEDURES (including preplacement): Exclude workers with evidence of chronic nervous or kidney disease from mercurial exposure. Medical examinations of exposed personnel should be done at quarterly intervals.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health*, 11:523, 1955.
2. ASHE, W. F., LARGENT, E. J., DUTRA, F. R., HUBBARD, D. M., and BLACKSTONE, M.: *Arch. Ind. Hyg. & Occup. Med.*, 7:19, 1953.
3. BARNES, E. C.: *J. Ind. Hyg. & Tox.*, 28:257, 1946.
4. CHOLAK, J., and HUBBARD, D. M.: *Ind. Eng. Chem., Anal. Ed.*, 18:149, 1946.
5. ELKINS, H. B.: Chemistry of Industrial Toxicology. John Wiley and Sons, Inc., New York, 1950.
6. GAUL, L. E., and UNDERWOOD, G. B.: *J.A.M.A.*, 140:860, 1949.
7. HILL, C. F.: Physical Review, 18:113, 20:259, 1922.
8. PATTY, F. A.: *Ind. Hyg. & Tox.*, 11:717, 1949.
9. RANDALL, M., and HUMPHREY, H. B.: U. S. Bur. Mines Circ. No. 7206, 1942.
10. VOUK, V. B., TOPOLNIK, Z., and FUGAS, M.: *Brit. J. Ind. Med.*, 10:69, 1953.

HYDROGEN FLUORIDE

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 3 parts of vapor per million parts of air, by volume (ppm).[1*]

(1) *Basis for Recommendation*: Animal and human experimentation.[6]

B. SEVERITY OF HAZARDS:

(1) *Health*: High. A respiratory irritant, when inhaled, resulting in pulmonary edema. Chronic low-grade exposures (not necessarily irritating) may result in bone accumulation of fluorides, with resulting abnormalities. Skin contact with the anhydrous liquid gives rise to severe and painful burns. Concentrated aqueous solutions may cause an early sensation of pain; more dilute ones may give no warning until slowly-healing ulcers develop.

(2) *Fire*: None.

C. SHORT EXPOSURE TOLERANCE: Concentrations below 0.1 mg/l were tolerated by animals for five hours without causing death; in man, after one minute, this produced a definite smarting of the skin, sour taste, and some conjunctival and respiratory irritation.[6]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 1.0-1.5 mg/l kills rabbits and guinea pigs within five minutes.[6]

II. Significant Properties

Hydrogen fluoride is a highly irritant and reactive gas. Its aqueous solutions are commercially available as hydrofluoric acid.

Chemical formula:	HF
Molecular weight:	20.01 (but some degree of polymerization, dependent on the temperature, may occur)
Specific gravity:	of liquid, 0.989 at 13.6°C
Boiling point:	19.4°C[8]
Relative density:	at 21.4°, 1.773 (air=1)[8]
At 25°C and 760 mm Hg, assuming no polymerization:	
1 ppm of vapor:	0.00082 mg/l
1 mg/l:	1223 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: Hydrogen fluoride is employed in the chemical industry and in refineries as a catalyst for the production of certain high-octane gasoline hydrocarbons. Aqueous solutions are used in various concentrations for frosting, etching, and polishing glass, and for removing sand from metal castings.

B. EVALUATION OF EXPOSURE:

(1) *Instrumentation*: Spectrophotometric,[2,5,10] fluorometric[9] or polarographic[7] methods may be used.

(2) *Chemical*: Collection in 1% sodium hydroxide in an evacuated bulb, with subsequent back titration of free alkali. Distillation with perchloric acid prior to the back titration is necessary if other volatile compounds are present.[3]

*Because of polymerization, it is more accurate to express these concentrations on a weight basis. With no polymerization, 3 ppm ≈ 0.0025 mg/l.

C. RECOMMENDED CONTROL PROCEDURES: Maintain workroom atmospheric concentrations below 0.0025 mg/l by process enclosure and/or ventilation. Use chemical type goggles and other protective clothing to prevent eye and skin contact.

IV. Specific Procedures

A. FIRST AID: Remove the individual promptly to an uncontaminated area. Administer 100% oxygen. Enforce bed rest for at least 24 hours. For cutaneous contact, flush the area with copious amounts of water, followed by swabbing with a 2.8% solution of aqueous ammonia. Immerse in a bath of water for a prolonged period. Injection of the tissue with 10% calcium gluconate around the affected area is helpful.

B. BIOCHEMICAL ASSAY: Urinary determinations may afford an indication of the degree of hydrogen fluoride absorption.[4]

C. SPECIAL MEDICAL PROCEDURES (including preplacement): Only intelligent and reliable persons should be permitted to work with this extremely hazardous substance. Persons with any form of respiratory disease and those with seriously impaired vision in one or both eyes should be excluded.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health*, 11:521, 1955.
2. BUMSTED, H. E., and WELLS, J. C.: *Anal. Chem.*, 24:1595, 1952.
3. DAHLE, D., et al: *J. Assoc. Official Agr. Chem.*, 21:459, 1938.
4. ELKINS, H. B.: The Chemistry of Industrial Toxicology. John B. Wiley and Sons, Inc., New York, 1950.
5. HORTON, A. D., et al: *Anal. Chem.*, 24:528, 1952.
6. MACHLE, W., THAMANN, F., KITZMILLER, K. and CHOLAK, J.: *J. Ind. Hyg.*, 16:129, 1934.
7. MACNULTY, B. J., REYNOLDS, G. F., and TERRY, E. A.: *Nature*, 169:888, 1952.
8. MELLOR, J. W.: A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. II. Longmans, Green and Co., Ltd., London, 1927.
9. POWELL, W. A., and SAYLOR, J. H.: *Anal. Chem.*, 25:960, 1953.
10. REVINSON, D., and HARLEY, J. H.: *Anal. Chem.*, 25:794, 1953.

Because of space limitations, it is impossible to list all methods of exposure evaluation. The selections have been made on the basis of current usage, reliability, and applicability to the usual industrial type of exposure. Any specific evaluation and/or control problem will involve professional judgment. This can best be done by professional industrial hygiene personnel.

Respiratory protective devices are commercially available. Their use, however, should be confined to emergency or intermittent exposures and not relied upon as primary means of hazard control.

A relative scale is used for rating the severity of hazards: nil, low, moderate, high, and extra hazardous.

HYGIENIC GUIDES COMMITTEE

WILLIAM E. MCCORMICK, *Chairman*
FRANCIS F. HEYROTH, M.D.
HERVEY B. ELKINS, Ph.D.
DAVID W. FASSETT, M.D.
WILLIAM B. HARRIS
MELVIN W. FIRST, Sc.D.
H. E. STOKINGER, Ph.D.
H. E. SEIFERT
CLYDE M. BERRY, Ph.D.

Hygienic Guides and Binders Available

INDIVIDUAL Hygienic Guides in loose-leaf form may be obtained from the American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan, at 25c each. Guides are now available for the following: Acetaldehyde, Amyl Acetate, Aniline, Benzol, Butyl Alcohol, Cadmium, Carbon Tetrachloride, Ethyl Alcohol, Formaldehyde, Hydrogen Fluoride, Hydrogen Sulfide, Mercury, Sulfur Dioxide, Trichloroethylene and 1,1,1,—Trichloroethane. An order blank may be found on page 84.

Also available now are flexible loose-leaf binders for the loose Hygienic Guide sheets. The binders have been especially designed to provide maximum protection and ease of handling of the Guides. They will be especially useful in keeping a permanent file. The binders are blue in color, with white lettering, and are fitted with ¾" rings. The price is $1.25, and they may also be ordered on the order blank on page 84.

◆ News of Local Sections

Chicago

THE CHICAGO Section meeting of January 4 was held jointly with the Chicago Chapter of American Society of Safety Engineers. The speaker was LEWELLYN HEARD, Ph.D., Research Department, Standard Oil Company of Indiana, Whiting, Indiana. DR. HEARD presented the "Fire Magic Show" for which he brought with him six packing cases of laboratory equipment. DR. HEARD'S interesting talk is punctuated by minor explosions, smoke rings and varicolored flames. It is understood that DR. HEARD has given his program in 15 states in which Standard of Indiana operates. His program can be highly recommended to any Local Sections that wish to have a different type of program that is not strictly industrial hygiene.

J. C. CALANDRA, M.D., Ph.D., Professor of Pathology, Medical School, Northwestern University, was the speaker at the February 1 meeting. DR. CALANDRA'S subject was "Toxicology—New Developments." Of particular interest was his discussion of the use of tracers in tissue culture studies.

Gulf Coast

ON JANUARY 25, the Gulf Coast Section met at the offices of the Harris County Health Unit in Houston. The program, "Demonstration of Noise Analysis Equipment," was presented by OTTO PAGANINI, District Industrial Hygienist, Texas State Department of Health. The Texas State Department of Health has recently purchased noise analysis equipment and is prepared to work with industry on noise problems.

On February 25-26, a joint meeting of the Texas Industrial Nurses Association and Texas Sections of AIHA was held at the Hotel Adolphus, Dallas. "Current Trends in Industrial Health" was the general theme for the meeting and also the title of the talk given by SEWARD MILLER, M.D., Director of Special Services, Department of Health, Education and Welfare. Other subjects discussed concerned noise and radiation control, placement of the cardiac in industry, changes in the Texas workmen's compensation law, and educational trends in industrial nursing.

Michigan (Detroit)

G. HOYT WHIPPLE, Ph.D., University of Rochester, was the speaker at the November 18 meeting. DR. WHIPPLE is associated with Atomic Power Development Associates, Inc., the group planning the installation of a nuclear power reactor in the Detroit area. He discussed radiation hazards and controls necessary for safe operations where radiation is involved.

On January 10, the Michigan Section was addressed by DONALD BIRMINGHAM, M.D., of the United States Public Health Service, who discussed his recent work with waterless hand cleansers. He outlined methods for testing cleansers, the various type of ingredients used and the results obtained.

Western New York

ON FEBRUARY 4, the Western New York Section met with the Western New York Society of Industrial Medicine & Surgery at the Eastman Kodak Company, Rochester. Our host was H. A. HANSON, M.D., Assistant Medical Director, Kodak Park Works. Following a tour of the Medical Department the formal program consisted of a discussion by GUSTAVE STREBEL, Industrial Optometrist, entitled "Operation Periphery—A Practical Approach to Occupational Vision Problems"; WILLIAM SUTTON, M.D., Resident in Industrial Medicine, spoke on "Ionizing Radiation and the Industrial Physician"; and EDWARD C. RILEY, M.D., Eastman Kodak Company, discussed "Control of an Occupational Disease Epidemic." Following the meeting, luncheon was held at the Kodak Park Cafeteria.

Ohio Valley

AT THE ANNUAL dinner meeting, held January 23 at Shuller's Wigwam, Cincinnati, the formal program consisted of a panel discussion on Air Pollution. Moderator of the panel was ANDREW D. HOSEY, Chief Engineering Services, Occupational Health Field Headquarters, USPHS. Panel members were ARTHUR C. STERN and DR. A. T. ROSSANO of the Air Pollution unit, Robert A. Taft Sanitary Engineering Center, JACOB CHOLAK, Director, Engineering Division, Kettering Laboratory, and CHARLES W. GRUBER, Chief, Bureau of Smoke Inspection, City of Cincinnati.

St. Louis

AT THE MEETING held December 14, LOUIS F. GARBER, Chief, Industrial Hygiene Division, Missouri Department of Health, discussed "How Serious is the Air Pollution Problem in Missouri."

NATHAN KOHN, JR., Ph.D., spoke to the Section meeting held February 28 on the subject of "Uses and Abuses of Psychological Testing in Industry."

Members nominated to serve as officers of the Section in 1956 are as follows: President: C. H. MEHAFFEY; President-Elect: JACK T. GARRETT; Secretary-Treasurer: ALICE C. DEVERS, R.N.; Director and Executive Committee Member: J. W. MILLER.

Northern California

A JOINT MEETING was held with the American Society of Safety Engineers on November 29. At this meeting the fields of activity in the two organizations were explored and reviewed. It was an opportunity to present the many specialties represented by the membership.

The Northern California Section served as a cooperating agency for The Second West Coast Noise Symposium held December 1 and 2, in Los Angeles.

On February 7, Alexander Simon, M.D., spoke to the Section on "Problems of Alcoholism in Industry." DR. SIMON is Professor of Psychiatry at the University of California, School of Medicine, and Assistant Medical Superintendent of the renowned Langley Porter Clinic, San Francisco. He has conducted research in the field of chronic alcoholism and is also engaged in medical practice for the treatment of alcoholics.

Nominated for officers for 1956 are the following: President: C. H. HINE, M.D.; President-Elect: GEORGE J. TAYLOR; Secretary-Treasurer: ROBERT MENDELL; Executive Committee: JOHN R. YOUNG.

At the March 8 meeting, PHILLIP R. HENDRIXSON, Technical Director, Electro-Chemicals Department, Du Pont, spoke on "Chlorinated Hydrocarbon Solvents." He discussed their uses, methods of safe handling and the hazards involved.

On March 20, the Section will hold a joint meeting with A.S.S.E. during the Third Annual Southern California Safety Congress. J. E. GILMORE, Safety Director, Johns-Manville Corporation, Lompoc, California, will speak on "Health-Safety Aspects at the Johns-Manville Corporation."

Southern California

AT THE DINNER MEETING January 12, the speaker was GEORGE TAYLOR, Industrial Health and Air Pollution Consultant, Berkeley, who spoke on "Industrial Health Activities in South America." MR. TAYLOR has recently returned from Brazil where he was in charge of Industrial Health Activities of the Institute of Inter-American Affairs. He discussed opportunities in the industrial health field in South America.

LEWIS J. CRALLEY, Assistant Chief, Division of Special Health Services, Occupational Health Field Headquarters, Cincinnati, was the speaker at the luncheon meeting on February 6. He discussed "Industrial Health Activities at the Field Headquarters."

North Texas

THE FOLLOWING officers were elected at the November 28 meeting: PAUL WITT, Chairman; DR. ROBERT J. POTTS, Chairman-Elect; MRS. WANDA HAMILTON, Secretary-Treasurer; CHARLES W. REED and DR. D. P. LAUGENOUR, Members of Executive Committee. Following the election of officers a panel discussion was held on the subject of "The Nurse's Participation in Industrial Hygiene." Panel members were MRS. LEE WYLIE, Industrial Nurse, Eastman Kodak Company; MARTIN C. WUKASCH, Chief, Industrial Hygiene, State of Texas Department of Health; DR. ROBERT J. POTTS, Medical Director, Magnolia Petroleum Company.

Washington-Baltimore

ON DECEMBER 14, a dinner meeting was held in the Officers' Club, Naval Gun Factory, Washington, D.C. DR. ANTHONY J. LANZA spoke on his experience of 'Two Score Years of Industrial Medicine." This was a particularly enlightening subject showing the progress that has been made within 40 years of industrial medicine in this country and can best be summarized by one example he cited. A number of years ago he met a physician in New York who had accepted a position in industry and as a result had lost his membership in the county medical society. This is in contrast to his recent meeting with the same physician who still holds the industrial position and now is president of the county medical society. DR. LANZA ended his talk with a challenge stating that the main problem on the horizon for the industrial workers is that of emotional stability and he feels as though a great deal of exploratory work is needed in this field.

At the same meeting there was an election of officers for 1956. DR. WILLIAM M. GAFAFER became past chairman, GEORGE S. REICHENBACH became the present chairman and HENRY N. DOYLE was elected vice-chairman. MRS. ELEANOR C. BAILEY became secretary-treasurer of the organization. MR. DOYLE, DR. GAFAFER and MRS. BAILEY are all with the U. S. Public Health Service, Occupational Health Program, while MR. REICHENBACH is the Industrial Hygiene Engineer of Bethlehem Steel Company, Sparrows Point, Maryland.

Georgia

AT THE MEETING on December 13, at Britton Dining Hall, Georgia Institute of Technology, DR. J. M. DALLA VALLE, Regent Professor, Georgia Institute of Technology, spoke on "Impressions of European Industrial Hygiene Practices."

Officers for 1956 are FREELAND F. CHEW, President; FRANKLIN KNIGHT, JR., President-Elect; HUGH LEE PARKER, Secretary-Treasurer.

New Jersey

ON FEBRUARY 16, at the Hotel Douglas, Newark, DR. HORACE W. GERARDE, Toxicologist at Esso Research and Engineering Company, and a member of the New Jersey Section, spoke to the group in an address called, "Of Mice and Men and Oil."

CLYDE M. BERRY, PH.D., formerly associated with Esso Standard Oil Company of New Jersey, is now Associate Professor of Agricultural Medicine, University of Iowa. GEORGE WILKENING, formerly of Esso Research and Engineering Company, has assumed the position vacated by DR. BERRY.

GEORGE BOYLEN, formerly with Esso, has joined the staff of the Connecticut State Department of Health, Hartford.

Michigan (Detroit)

ON FEBRUARY 14, the Michigan Industrial Hygiene Society held a joint meeting with the Detroit Industrial Physician's Club at Bagozzi's Ever-Joy Chop House in Detroit. The guest speaker for the evening was DR. ROBERT A. KEHOE from the Kettering Laboratories at the University of Cincinnati. DR. KEHOE discussed the two-point attack for proper lead control. He stated that engineering control was necessary in the plants to eliminate excessive exposures in the way of lead dust or fume. On the other hand, he stated that medical control in the way of blood analyses and urine analyses for lead was of primary importance. He felt that it was the only way in which an accurate measure could be made of whether or not employees were being exposed to high concentrations of lead.

✦ Obituary

HAROLD A. THIEMANN, Engineering Technical Supervisor in the Hartford Accident and Indemnity Company, died November 18, 1955, while in Pittsburgh attending meetings of the Industrial Hygiene Foundation and the American Standards Association.

MR. THIEMANN was born in Chicago in 1910. He was educated in Chicago public schools before attending the University of Illinois. He was graduated with a B. S. in Chemistry in 1933. He was a member of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION and represented Hartford on the Special Hazards Sub-Committee of the Association of Casualty and Surety Companies. He was also on the Flammable Liquids Committee of the National Fire Protection Association. He is survived by his widow, MRS. SALLY O. THIEMANN, of 20 Manchester Street, Hartford, Connecticut.

FOR SALE: *J. Ind. Hyg. & Toxicol.*, Vols. 22-31 (1940-49) incl.; *Arch. Ind. Hyg. & Occup. Med.*, Vols. 1-10 (1950-54) incl.; *Ind. Hyg. Quart.*, Vols. 11-16 (1950-55) incl. Unbound. Prefer to sell all as one lot but may sell in parts. Offers will be received by Samuel Moskowitz, 1347 E. 17 St., Brooklyn 30, N.Y.

Listings for

CONSULTANTS

and

SERVICES

in

INDUSTRIAL HYGIENE

AIHA QUARTERLY